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14. ABSTRACT

An instrumented burst tester was developed that is capable of determining the precise internal pressure level at which a polytray package develops a small leak or explosively bursts. The total cost of fabricating a this burst tester is approximately $5,000. Burst test results correlated well with peel strengths. It was found that non-defective seals from Vendors 1 and 3 performed very similarly. Defective polytray seals (entrapped matter, blisters, etc.) from Vendor 1 showed a large decrease in seal strength, while polytrays from Vendor 3 with short seal and entrapped matter defects showed no decrease in seal strength compared to non-defective seals. Finite element modeling showed that an internal pressure burst test adequately stresses the seal in all three possible crack propagation modes and another test to specifically test the seal in shear is not necessary. The non-contact ultrasonic inspection methods studied (airborne and laser-based) were either too slow or too insensitive to be feasible for 100% online inspection of polytrays. The heat seal failure path always migrated to polyester/nylon bond in quad layer lid film before final failure of the seal. Based on the obtained

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"Development and Evaluation of Integrity Assessment Tests for Polymeric Hermetic Seals"

Final Report

Kevin Kit

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Abstract

An instrumented burst tester was developed that is capable of determining the precise internal pressure level at which a polytray package develops a small leak or explosively bursts. The total cost of fabricating a this burst tester is approximately $5,000. Burst test results correlated well with peel strengths. It was found that non-defective seals from Vendors 1 and 3 performed very similarly. Defective polytray seals (entrapped matter, blisters, etc.) from Vendor 1 showed a large decrease in seal strength, while polytrays from Vendor 3 with short seal and entrapped matter defects showed no decrease in seal strength compared to non-defective seals. Finite element modeling showed that an internal pressure burst test adequately stresses the seal in all three possible crack propagation modes and another test to specifically test the seal in shear is not necessary. The non-contact ultrasonic inspection methods studied (airborne and laser-based) were either too slow or too insensitive to be feasible for 100% online inspection of polytrays. The heat seal failure path always migrated to polyester/nylon bond in quad layer lid film before final failure of the seal. Based on the obtained results recommendations were made regarding use of the instrumented burst test, testing protocol, future modifications to the burst test equipment, and future selection of polytray heat seal equipment.

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1 Introduction

Rejection of polytrays due to seal defects is a large problem that results in losses in money as well as in the production capability of ration producers. At the beginning of this project, a reliable mechanical test that can accurately assess seal integrity did not exist. Such a test is required in order to quantitatively determine the effect of processing conditions and possible defects on the strength, durability, and integrity of the seal. This would give producers a better understanding of the process and allow them to create better seals, leading to reductions in reject rates and costs and an increase in production capacity. Current burst testing does not seem to be an adequate method for this purpose and a new test procedure must be developed.

In addition to a reliable destructive test, an online nondestructive test could inspect 100% of sealed packages and provide information about seal integrity. The implementation of such an inspection system would have several benefits including 1) a better understanding of how processing conditions affect seal integrity, 2) an automated, immediate alert to the presence of seal defects, and 3) a prediction of which packages are likely to fail inspection after retorting.

Phase I of this project focused on the development of a reliable and quantitative destructive burst test and a feasibility study for using online nondestructive ultrasonic inspection techniques for 100% inspection of sealed polytrays.

Phase II of this project focused on using the instrumented burst test developed in Phase I to evaluate the burst strengths of a large number of polytrays with and without sealing defects. The results of these tests were used to make recommendations on the severity of specific sealing defects and on a burst test protocol for future testing.

2 Phase I

2.1 Objectives

The initial phase of this project had two objectives. The first was to develop reliable destructive mechanical tests which would accurately measure the strength of any seal and to assess the extent to which common seal defects (e.g., entrapped matter, delamination, etc.) degrade seal integrity. The second objective was to determine the feasibility of using non-contact ultrasonic inspection to detect and predict the severity of seal flaws.

2.2 Tray Production and Acquisition

In order to successfully categorize sealing defects, polytrays with both artificial and naturally occurring defects had to be acquired from the manufacturing facilities. Many of these packages, especially with artificial defects, had to be manually produced at the manufacturing facilities. Polytrays, both empty and media filled with naturally occurring sealing defects ranging from excellent to very poor were also acquired from three vendors herby designated as Vendor 1, Vendor 2, and Vendor 3.

2.2.1 Trial 1

Trial 1 for polytray production took place at Vendor 1 on June 3, 2003. Sample trays were made for both mechanical and microbial challenge testing. Artificial channel defects across the seals were created using fine nickel-chromium (Ni-Cr) wires with diameters of 50.8, 127, 254 and 381 microns. The wires were gently taped across the edge of the trays in various positions before sealing. Some experimenting with the wire placement was required before tray production could begin. A potential 12.7 micron wire was used and proved to be too fine for production. The 12.7 micron wire would break as the tray was sealed and the wire could not be pulled out of the seal to create the channel defect. A PTFE (polytetrafluoroethylene) spray was used as dry release agent to aid in the removal of the more delicate 50.8 and 127 micron wires from the seals of the trays.

A total of 60 empty trays were produced for mechanical testing; 10 trays for control (no defects), 10 trays for each wire size (four wire sizes), and 10 trays with all the wire sizes in the seal (see Appendix A). Each wire was removed after the sealing and retort process to create a channel leak in the seal. The empty trays were used for non-destructive and destructive testing. An additional 9 empty trays were made with the placement of a starch solution on the seal before sealing; 3 different viscosity solutions (3, 4, and 5% starch in water) in 3 different positions on the seal. These trays were used for mechanical testing as well and the production of polytrays with entrapped matter defects will be examined further in Trial 2.

A total of 80 media filled trays were produced for the microbial challenge testing (see Appendix A). Media was produced and used to fill trays containing various artificial defects. Defects were created using the same nickel-chromium wires as discussed previously. Five trays for each wire size (four wire sizes) five defect free samples were made to be dipped into three different microbial environments. An additional five positive control samples were made to be post cool inoculated. Two 10L pots were used to make a 20L batch of media. Each pot contained 10L of water, 300g tryptic soy broth and 500g (5%) starch (*Ultraspearse*). The solution was heated until boiling and was continuously stirred with a whisk until solids were completely dissolved. A total of 6.5 batches were made or a total of 130L of media.

Media was slowly poured into the trays with the various wires in place and the trays were then sealed under the following conditions: line speed of 16 trays/min, sealing temperature of 232° C, and a sealing pressure of 5.5 bars or 80 psi. Ten to fifteen trays at a time were put into production at random times during the production day (see Appendix A). Once all trays were produced, they were put through the retorting process using the ICON 2000. The retorting process required about 3.5 hours for each cycle. The sealed retort vessel was pumped with steam with a slow ramping temperature to around 124.5°C and then a cool down spray was used to return packages to room temperature. Tables in Appendix A shows the exact retort conditions used for our trays.

As stated previously, nine additional empty trays were made with artificial defects by placing different viscosity solutions on the seal area before sealing. For each viscosity solution, one drop was placed on three trays; the short side of one tray, long side of one tray, and the corner of one tray. After sealing, it was clearly seen that there were defects in the seal where the drops had been placed. Future experiments will include a variety of different media to understand real processing/sealing problems encountered at the plant.

2.2.2 Trial 2

Polytrays were again manufactured at Vendor 1 in February 2004. The same process was used here for Trial 2 to fill and seal the packages. The 254 and 381 micron wires were not used in this trial because Trial 1 testing proved the channel defects to be too severe. The 50.8 micron wire was used in this trial to create channel defects. Non-defective samples were made along with samples with entrapped matter, see Appendix A.

To understand some of the problems occurring in process, soy bean oil, starch solution (6.5%) and blanched noodles were placed across the tray before sealing. This in turn creates an artificial defect in the sealing area. The defects were clearly visible and samples could then be cut from the area surrounding the defect for mechanical testing.

2.2.3 Acquired Polytrays

Several sets of polytrays were received at the University of Tennessee for testing. As the polytrays were received, they were documented and labeled accordingly. The condition of the as-received polytrays was recorded and defects were classified before testing was conducted. The first polytrays received were from Vendors 2 and 3. These packages were empty, meaning they were sealed with no media inside. The polytrays had no as-received visual defects in the seal area. These packages were used for initial peel, tensile, and burst testing to gain a better perspective on the seal strength of these polytrays. The preceding polytray sets were labeled as Vendor 2A and Vendor 3A.

A third set of polytrays received was from the Center for Advanced Food Technology at Rutgers University. These polytrays were also sealed empty. These polytrays had some major sealing defects mainly due to deformed (high variance) flanges on the polymer tray itself. As lid stock (quad-layered film) was heat-sealed to the tray, the resulting seal contained many areas that were not bonded and thus “short seals” were created. Some areas of the lid-stock did not bond at all with the tray; voids, or large channel defects, were created within the seal. Each polytray was labeled and each defect was taken into consideration and documented. A good seal is roughly 5 mm in width from the inside of the flange to the outside. A “short seal” defect was defined as any area of the seal that was less than 5 mm in width. The defect was then given as a percentage of a good seal remaining after the sealing process. Figure 1 shows a schematic drawing of a “short seal” defect. Shaded regions represent areas of the seal that remain unbonded after sealing process. These “short seal” polytrays were used for both peel testing and burst testing.

The last set of polytrays was sent from Vendor 3. These packages were mainly used for the instrumented version of the burst tester and were labeled as Vendor 3B. These polytrays were sealed with media inside such as baked beans, spaghetti, and meatballs. A large variety of defects was represented in this set of polytrays. Short seals, air bubbles, and wrinkles of varying sizes were all visible within the seals of these polytrays.

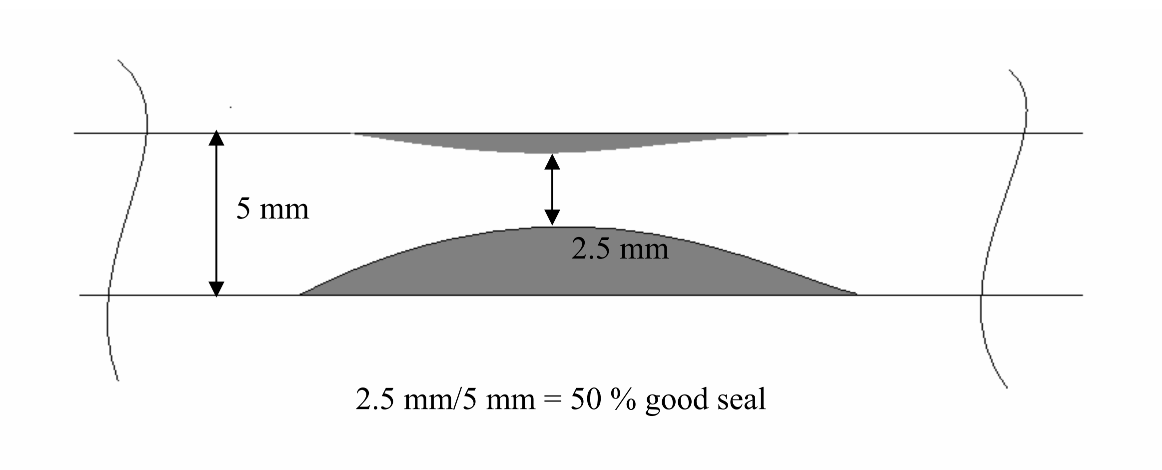

Figure 1. Schematic drawing of a “short seal” defect and calculation of remaining good seal after sealing process.

2.3 Peel Testing

Peel testing was performed using the T-Peel test according to ASTM D1876-01 [28] standard in conjunction with the ASTM F88 – 00 [29] standard test method for seal strength of flexible barrier materials. Specimens deviated from the standard because the bonded area or seal width is only about 5 mm. Samples were cut from the polytrays in 1 inch wide sections. Non-defective polytrays were tested first to understand the seal integrity of polytrays deemed as in good condition. From these results we compared results from the samples cut from the polytrays surrounding the natural and artificial defects. The Instron® tensile testing machine was used for this experiment. A 100 lb load cell was used with a cross-head speed of 0.2 inches/minute. The sample was placed in between the grips, having a gage length of 0.5 inches, with 100 psi gripping pressure. Peel tests were conducted on the polymer trays in batches as they were sent to the University of Tennessee, Knoxville and as they were made at the manufacturing facilities. Figure 2 shows an example of a T-peel test specimen from ASTM D1876-01.

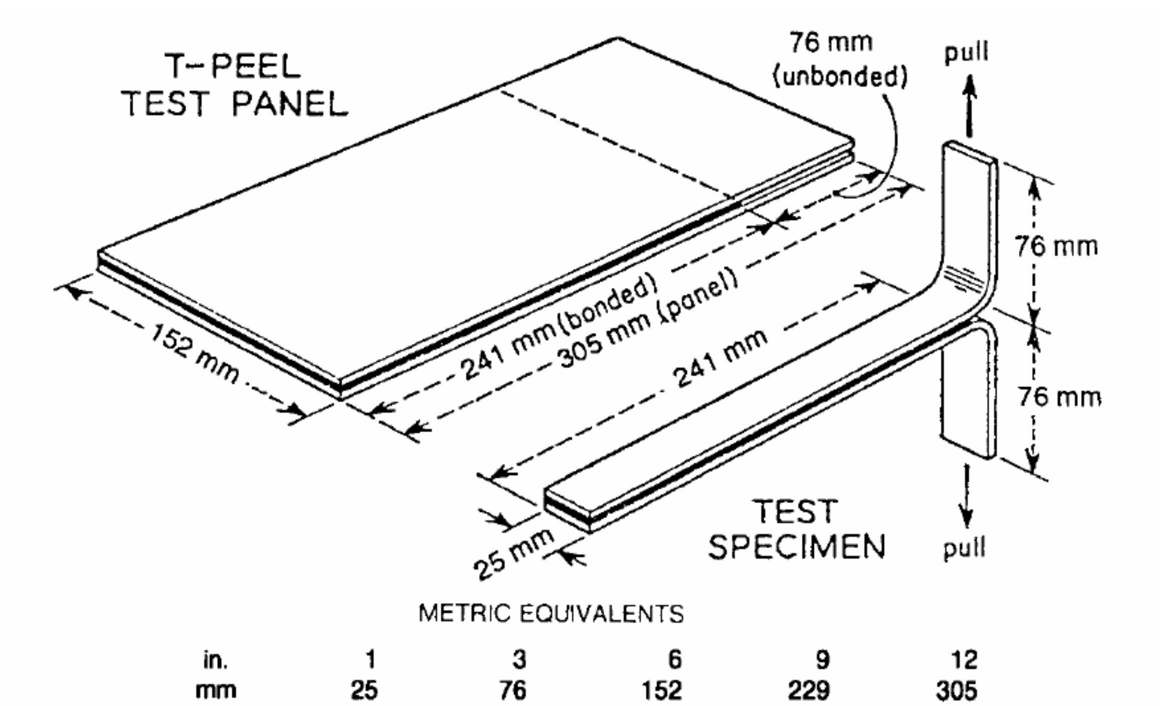

Figure 2. Example of T-peel specimen from ASTM Standard D1876.

2.3.1 Peel Testing Samples

For each of the sample sets designated as Vendor 2A and Vendor 3A, forty samples were cut from five polytrays with no visual defects to be used as the testing population.

A set of defective polytrays tested was sent from the Center for Advanced Food Technology at Rutgers University in New Jersey. These polytrays had many visual defects; mainly short seal defects due to deformed (high variance) flanges on the polymer tray itself. These defects were described earlier. As lid stock (quad-layered film) was heat-sealed to the tray, the resulting seal contained many areas that were not bonded and thus "short seals" were created. Again, some areas of the lid-stock did not bond at all with the tray. Voids, or large channel defects, were created within the seal and the peel tests verify that fact with low peak load.

The samples were cut from several of the polytrays at random. No specific defect was cut to be tested, but rather a good representation of the defects on the polytrays was obtained. Samples were tested with areas of the seal within the sample ranging from 0% to ~90% good seal. A total of ten "short seal" samples were used for the sample sets. Rutgers polytray samples that appeared visually intact (100% good seal) were also tested in two subsets. The seals that were most visually sound were selected and cut from the polytrays. A total of seventeen samples were tested.

The last set of peel tests involved polytrays with artificial defects such as entrapped matter made during Trial 2 at Vendor 1. Surprisingly, the entrapped oil and starch samples performed just as well or better than the control (defect free) samples produced. The entrapped noodle samples, on the other hand, performed poorly compared to the control samples. There is a wide variation in all of the sample groups especially in the control samples. Again, this variation in the control samples may be due to uneven sealing or processing conditions on the particular production day, even though visual inspection showed no difference in seal appearance before the samples were tested. SEM or optical microscopy was not used in this project. These particular polytrays with entrapped matter were burst tested as well and the data was correlated to the peel test data obtained.

2.3.2 Peel Testing Results

All peel testing results can be seen in Table 1 and Figure 3. Table 1 shows the maximum and minimum peak loads for each sample within its respective sample group as well as the standard deviation and mean value. Vendor 3 polytrays have the strongest seals with an average peak peel of 32.35 lb_f/in but at the same time have the highest standard deviation of all the polytray sets with a corresponding value of 7.67 lb_f/in. The Vendor 2 polytrays and good samples (100% good seal) from the Rutgers polytrays seem to have the lowest standard deviation of all. The entrapped noodle samples proved to be the worst performing of all peel test sets with an average peak value of 15.31 lb_f/in and the lowest recorded peak force value at 7.17 lb_f/in.

Table 1. Analysis of all peel test data showing maximum, minimum, average, and standard deviation. Trial 2 polytrays were produced at Vendor 1.

Peel Samples	Maximum Peak Peel (lbf/in)	Minimum Peak Peel (lbf/in)	Average Peak Peel (lbf/in)	Std Dev (lbf/in)
Vendor 2A - Non-defective	30.25	17.41	23.77	3.35
Vendor 3A - Non-defective	43.83	18.27	32.36	7.68
Rutgers Polytrays - Non-defective	31.21	20.53	25.49	3.38
Rutgers Polytrays - Short Seals	24.01	8.42	18.86	4.49
Trial 2 - Non-defective	27.83	11.72	19.53	5.02
Trial 2 - Entrapped Oil	29.44	18.01	25.20	3.65
Trial 2 - Entrapped Starch	32.49	17.35	23.856	6.07
Trial 2 - Entrapped Noodle	23.54	7.17	15.31	5.84

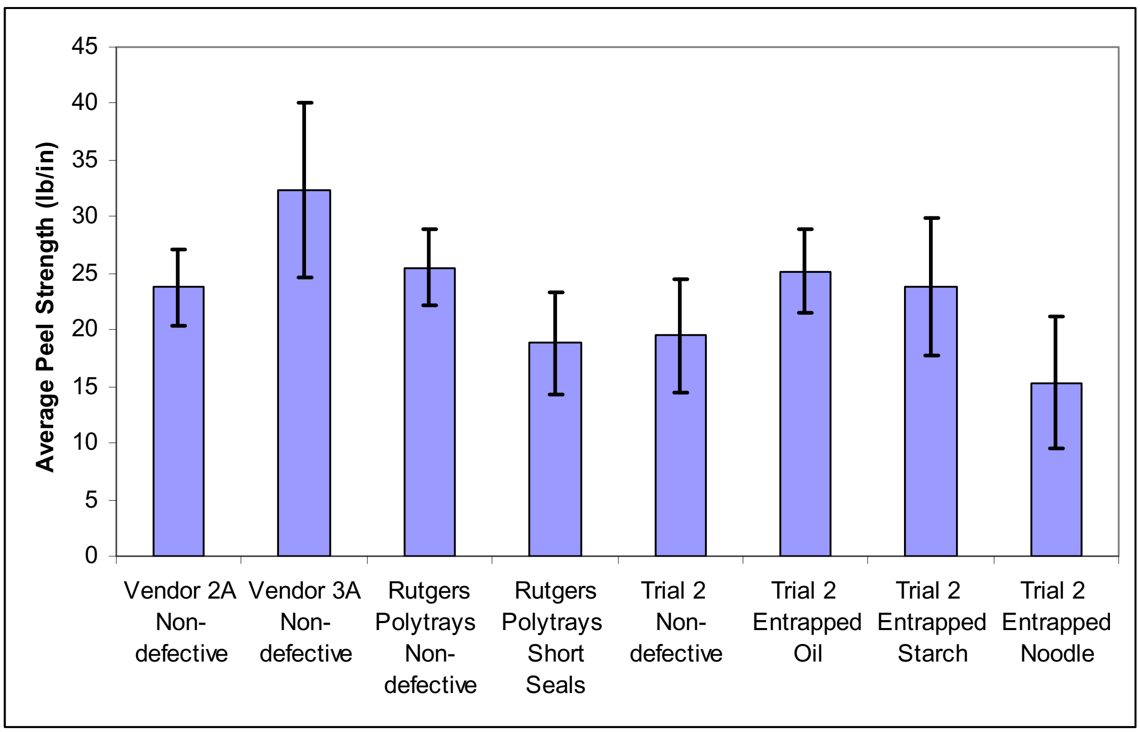

Figure 3. Average peel strength data for all polytrays. Error bars correspond to +/ one standard deviation. Trial 2 polytrays were produced at Vendor 1

2.4 Burst Testing

ASTM standard F 2054 – 00 [31] was used as a basis for the design of a burst test system in this project. This standard test method describes burst testing of flexible package seals using internal air pressurization within restraining plates. A burst test (pressurized polytray) was developed to be similar to the current testing performed at the manufacturing facilities. The burst test was used to compare results and correlate data with peel tests for the seal strength of the polytrays. In order to detect leaks, a burst test system had to be built that would constantly monitor the air flow through the polytray versus increasing air pressure within the polytray. The first system was built as a parameter check for a future PC interfaced system. The initial system set up was developed to check for the minimal air flow or leak that could be detected.

2.4.1 Initial Burst Testing

The first system assembled consisted of a regulator, flow meter, a pressure gauge close to the package, a release valve, and the polytray chamber. The flow meter ranged from 0.0 mL/min to 110 mL/min with glass ball inserted into the tube and 0.0 mL/min to 250 mL/min with the steel ball inserted into the tube. Figure 4 shows the regulator and air flow meters run in series to the package chamber. Figure 5 is a picture of the burst chamber designed to hold the package in place while pressurization is taking place. Designs for the burst chamber were completed using the Solidworks® software and can be seen in Appendix C. Air was transferred into the polytray using 0.25 inch Tygon® rubber tubing. A 0.75 inch hole was drilled into the side of each polytray before testing. The polytray was then placed into the burst chamber. Once the polytray was in the burst chamber, the rubber tubing was inserted into the hole in the side of the polytray and the burst test was initiated.

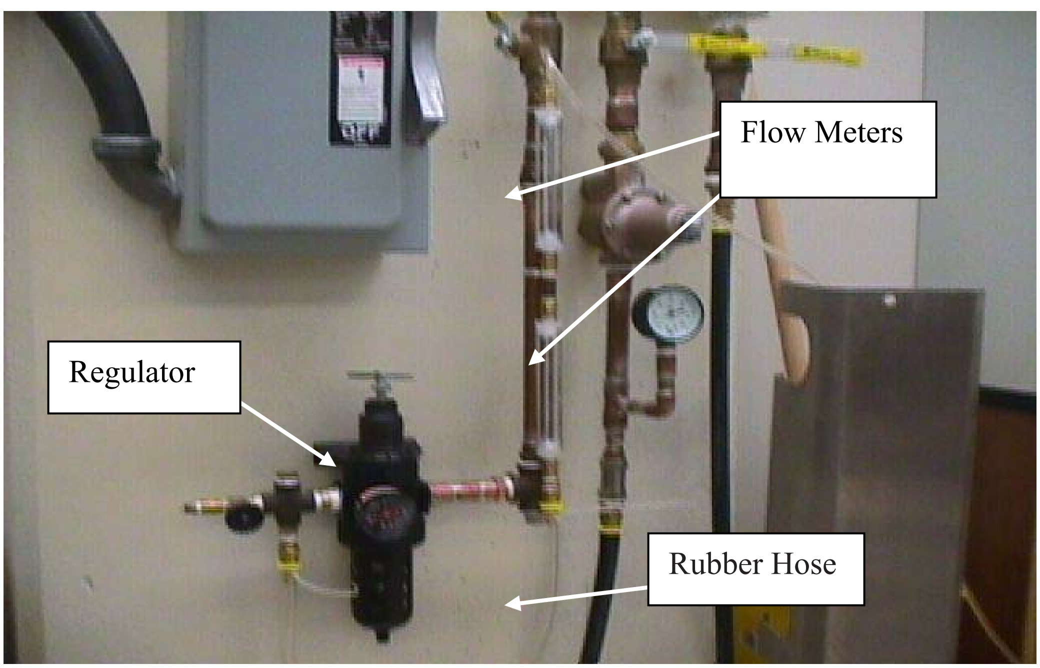

Figure 4. Air flow system for the burst tester.

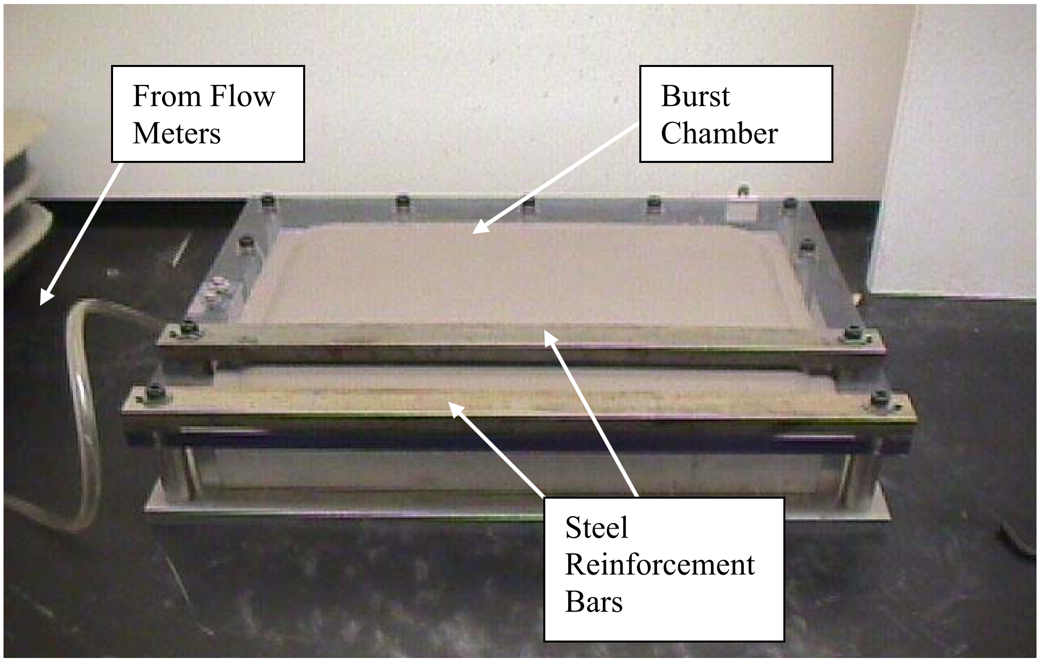

Figure 5. Picture of the burst chamber used for the burst testing.

Once the system was complete, three packages without defects were run with increasing pressure from 0 to 40 psi for the evaluation. One package burst up to 40 psi, one package did not burst at 40 psi, and one package burst at 30 psi. Flow meter readouts for all three evaluation experiments were from 0 to 0.5 mL/min which indicates that the system connections are sealed nicely. The small air flow present, 0.5 mL/min was probably due to the creep, or peel, of the seal under increasing pressure.

The polytrays produced during Trial 1 were used for the initial burst test experiments. Non-defective packages were run for evaluation of the air flow system to the package and to check for leaks. Five packages of each artificial channel defect (50.8, 127, 254, and 381 microns) were tested. Five packages that had "short seals" were also tested (50 – 80% good seal in a certain area). Pressure versus flow was monitored and plotted as applicable. Only two polytrays with the 50.8 micron channel defects were tested. It was extremely difficult to remove the 50.8 micron wires from the seal without breaking, and several polytrays were lost in the attempt to remove the wire (wires are still in the seal).

The packages produced during Trial 1 at Vendor 1 were used extensively for the first round of burst testing. Several control polytrays were used for evaluation of the air flow system to the polytray. Five packages of each artificial channel defect created having diameters of 50.8, 127, 254, and 381 micron were tested. An additional five packages from the Rutgers polytrays, having short seal defects, were also tested. The Rutgers polytrays had short seal defects ranging from 50 to 80% good seal in a certain areas. The pressure versus flow was monitored and plotted as applicable. Only two polytrays containing the 50.8 micron channel defects were tested due to the extreme difficulty of removing the 50.8 micron wire from the seal without breaking.

Air flow versus pressure was monitored and plotted which can be seen in Figure 6. Air flow was detected going into the polytray with as little pressure as 5 psi. The sharp increase in air flow on the plot, around 20 psi, was most likely due to human error in estimation on the analog flow meter.

Figure 7 shows an example of a polytray with a 50.8 diameter micron channel defect that had burst at a pressure of 30 psi. The X’s mark the area of failed seal after failure. It cannot be determined if the seal initially failed at or around the defect site based on data and observation, but this is a possibility.

Five polytrays with 127 micron diameter channel defects were tested from 0 to 30 psi. The flow versus pressure was monitored and then plotted as above. Every polytray burst at or around 30 psi. Because there is no digital readout for the pressure gage, the actual value at which the polytrays burst can not be determined with great accuracy. Only one of these polytrays did not fail in the seal area surrounding the channel defect.

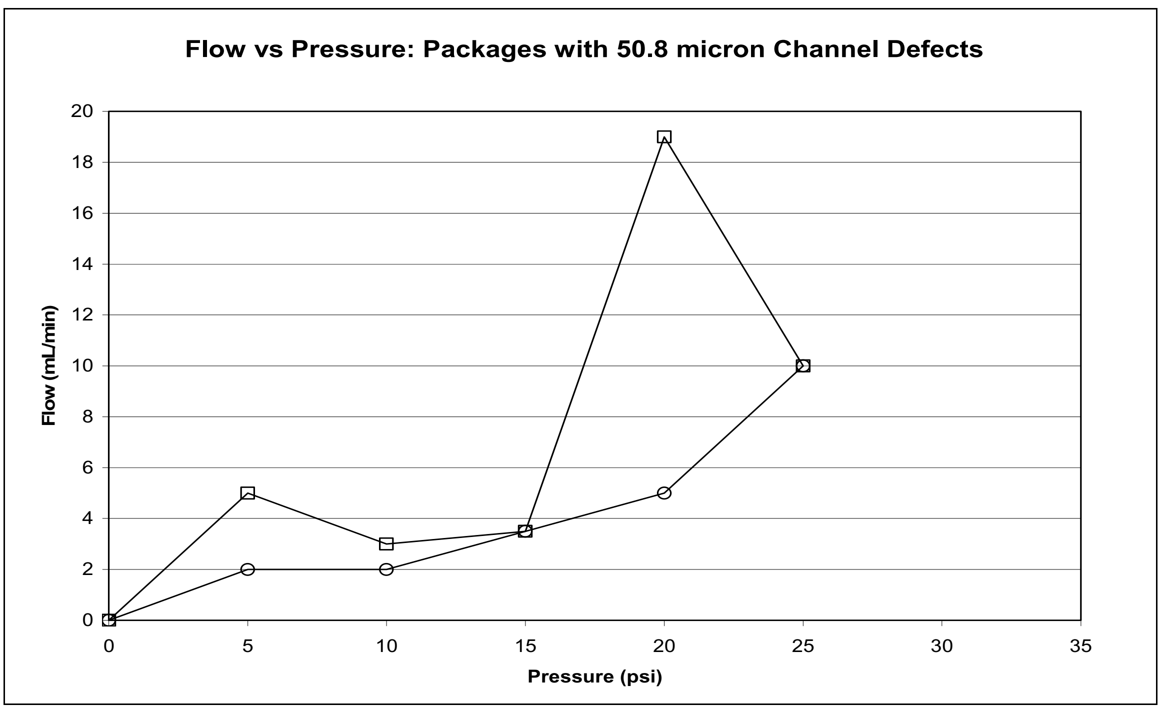

Figure 6. Plot of the air flow versus the increase in pressure for polytrays with 50.8 micron diameter channel defects.

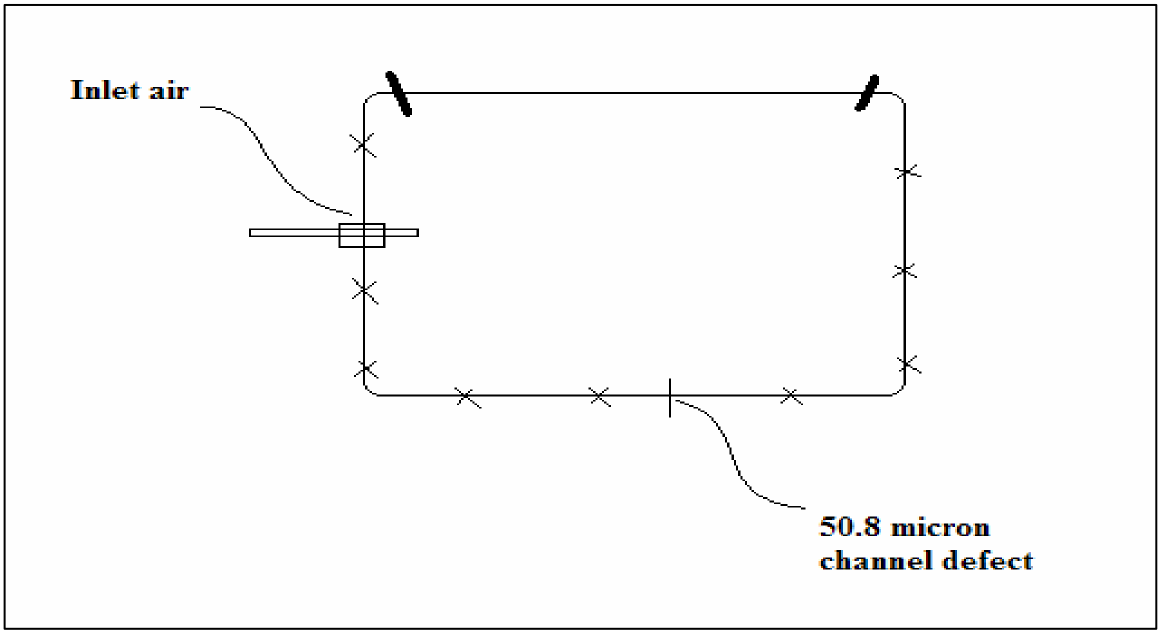

Figure 7. Example of the 50.8 micron channel defect package after failure.

Figure 8 is a plot of the air flow versus increasing air pressure for the 127 micron diameter channel defects. All 127 micron diameter channel defect polytrays tested had detectable leaks. A more linear pattern was seen in this experiment as compared to the polytrays with the 50.8 micron diameter channel defects. All five polytrays burst between 25 and 30 psi. Figure 9 is an example of a package with a 127 micron channel defect that failed due to the high pressure, but the seal area surrounding the defect did not fail. The X's mark the area of burst seal. The other four polytrays all burst around the defect site, but determining exactly where the failure initiated is unclear based on the data and observation.

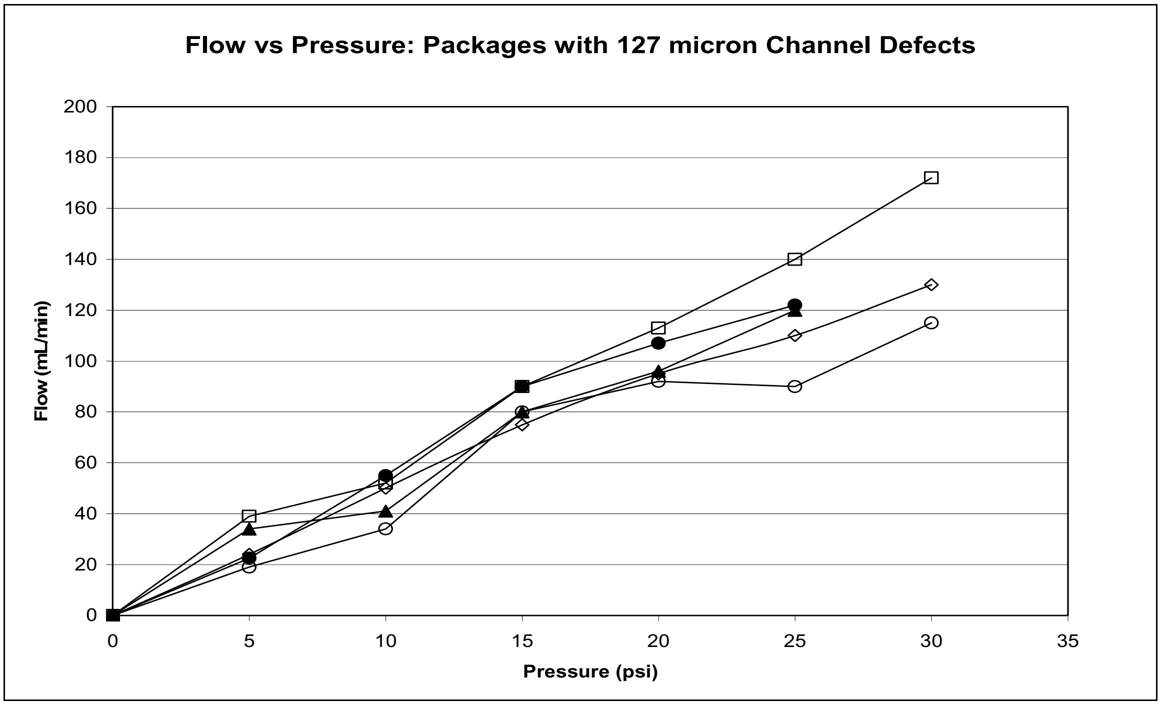

Figure 8. Plot of the air flow versus increasing air pressure within the 127 micron diameter channel defect polytrays.

Five polytrays were tested with the 254 micron diameter channel defects. Three of the polytrays burst at 35 psi. Two polytrays did not burst, but rather formed severe leaks in the area surrounding the sealing defect. Along with the severe leak, delamination, or peel of the seal, occurred at and around the area surrounding the channel defect. Once these polytrays leaked so severely, the polytray could no longer maintain regulator pressure. Air flow with an internal pressure of 5 psi and greater was off the scale of the flow meter. A plot of the pressure versus air flow could not be generated because data could not be collected from the flow meter. Figure 10 is an example of how the seal delaminated around the 254 micron diameter channel defect.

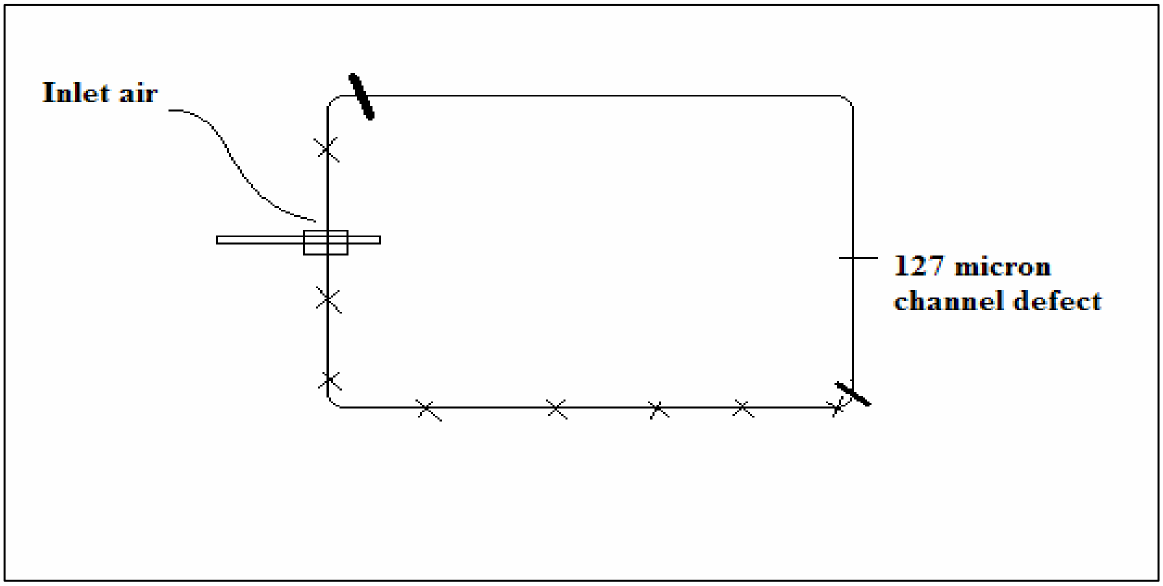

Figure 9. An example of a package with a 127 micron channel defect that failed but the seal area surrounding the defect did not fail.

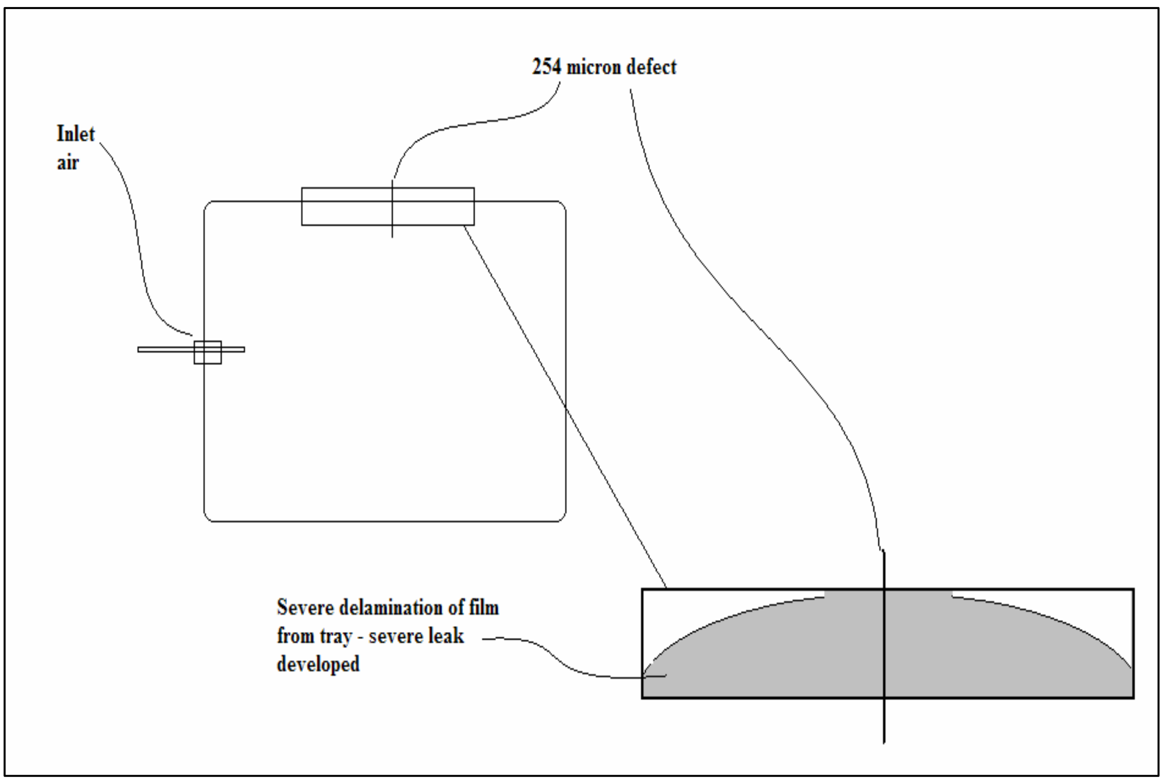

Figure 10. Example of polytray with a 254 micron diameter channel defect that did not burst, but formed severe delamination around the defect site.

Similar results were seen for the polytrays with 381 micron diameter channel defects. None of the polytrays burst due to the increasing pressure. The leaks became larger with increasing regulator pressure; 0 to 30 psi. The polytrays could not maintain the regulator pressure because the flow was again too great through channel defect. Plots for air flow versus pressure could not be generated for these polytrays because the flow meter data was off the scale.

Air flow versus pressure for the polytrays with various short seal defects can be seen in Figure 11. The development of leaks could be seen in these samples. Five polytrays from Rutgers with short seal defects were also tested. Three of these polytrays burst at 30 psi; one polytray with an seal area having 60% good seal and two packages with seal areas having 50% good seal. One polytray having an area of the seal with 70% good seal did not burst but rather leaked severely around 30 psi at the defect site. The last polytray, containing another area with a 70% good seal defect maintained pressure to 40 psi and did not burst. These results demonstrate that visual inspection and interpretation of a defect is not always correct and this issue needs to be evaluated carefully.

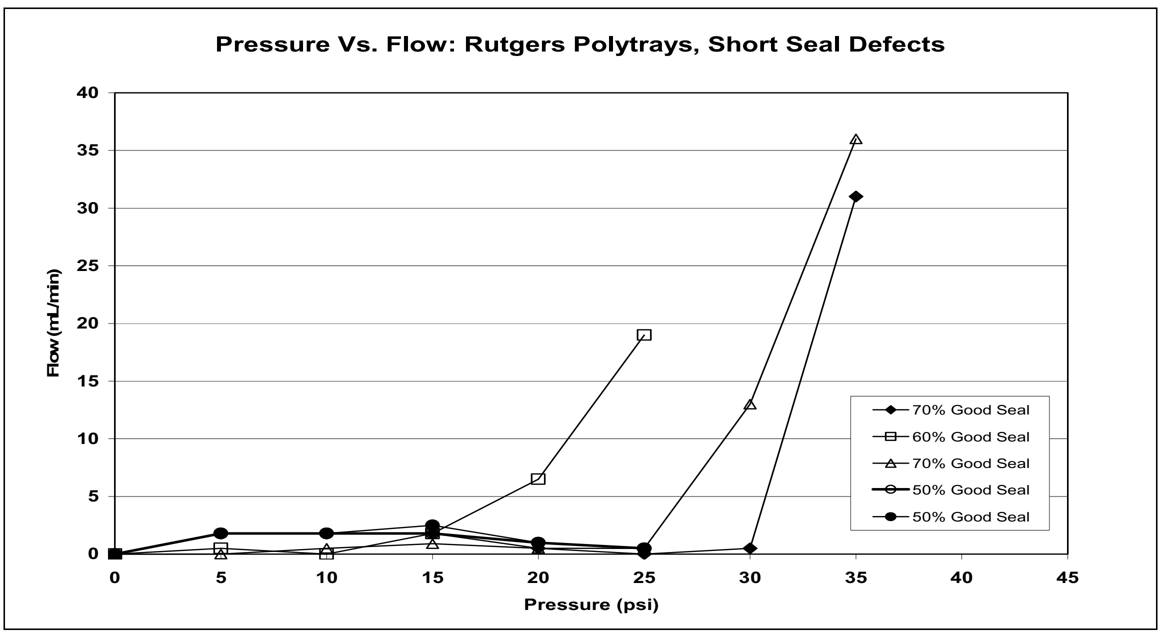

Figure 11. Plot of the pressure versus air flow for the packages with short seal defects.

2.4.2 Instrumented Burst Testing

The analog burst tester was replaced by the PC interfaced system after the polytrays from Trial 1 were tested. The PC integrated system uses the Labview® 7.0 software in conjunction with the National Instruments® hardware. The maximum measurable air flow was 20 mL/min with an accuracy of 0.2 mL/min. As the polytray was pressurized and reached equilibrium, the air flow fell to 0.0 mL/min when there was no leak in the polytray.

The internal components of this system can be seen in Figure 12. Inside the system enclosure, the compressed air line passes through a regulator, a volumetric flow meter, a relief valve, and a pressure transducer before exiting the system and entering the polytray to be tested. The solenoid relief valve is controlled by a solid state relay. The regulator and relay are controlled by DC voltages supplied by a National Instruments DAQ data acquisition card. Electrical connections to the PC are made inside the shielded terminal box seen in the upper right corner of Figure 12. Voltage data is collected from the flow meter and pressure transducer using the same terminal box. The system requires standard 120V AC power, a source of compressed air between 60 and 150 psi, a PC with a National Instruments DAQ data acquisition card, and an appropriate National Instruments cable. The PC which interfaces with this system will be able to run an executable program supplied by the author.

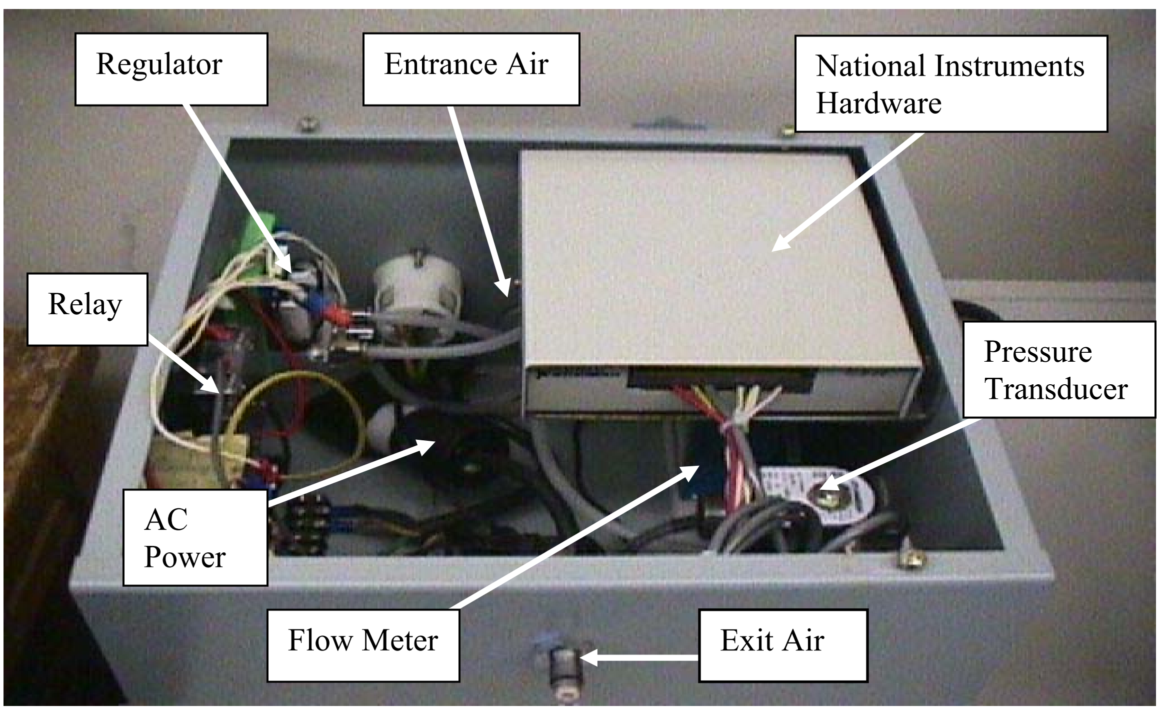

Figure 12. Picture of PC integrated burst test system.

The media filled samples from Vendor 2 with various defects were tested and used for evaluation of the PC integrated system. Polytrays were tested until failure and data was recorded and saved through the Labview® 7.0 software. The initial pressure was set to 5 psi and a step program increased the internal pressure 5 psi every five minutes. This allowed ample time for the polytray to pressurize while allowing the flow rate to return to 0 mL/min if a leak did not develop. The pressure continued to rise until the polytray failed.

Instrumented burst tests were conducted for polytrays made during Trial 2 at Vendor 1. Three of each of the following polytrays were pressurized until failure: non-defective samples, samples with entrapped 6.5% starch solution, samples with entrapped soybean oil and samples with entrapped blanched noodles. All polytrays failed at pressures less than 35 psi. The non-defective sample, entrapped oil, and entrapped starch all performed similarly. The entrapped noodle polytrays did perform as expected producing leaks and failing at lower pressure values than the other polytrays.

The results from these burst tests (three polytrays for each defect) correlated very nicely with the peel results for the same polytrays seen previously. A comparison of the burst and peel tests data for these polytrays along with the Rutgers polytrays can be seen in Figure 13. A correlation plot given in Figure 14 displays peel (lb_f/in) versus burst strength (psi) for the various polytrays tested. Peel and burst tests do correlate fairly well.

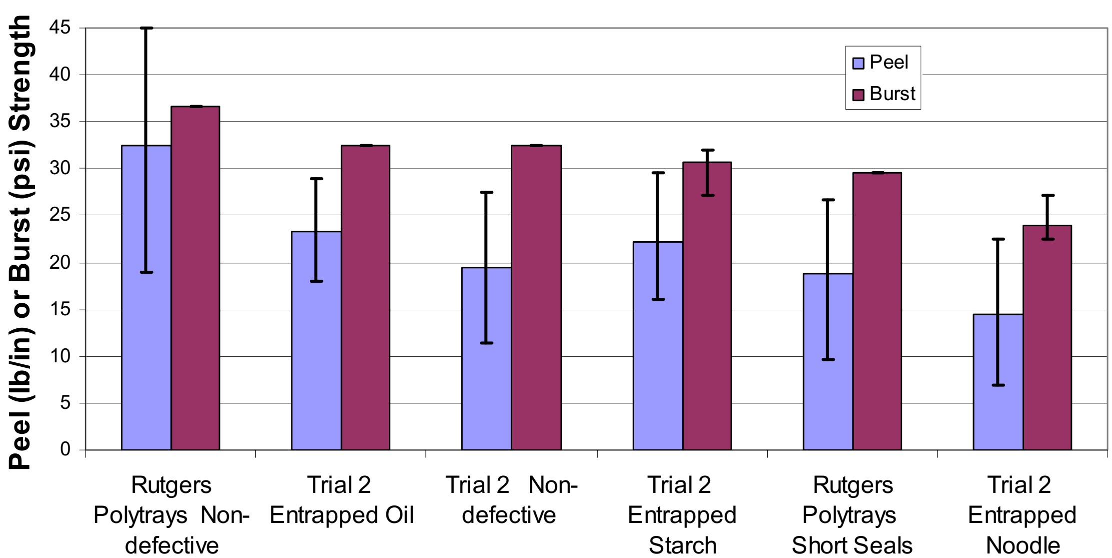

Figure 13. Comparison of burst test and peel test for Rutgers and Trial 2 polytrays. Error bars indicate maximum and minimum measurements for burst strengths and +/ one standard deviation for peel strengths.

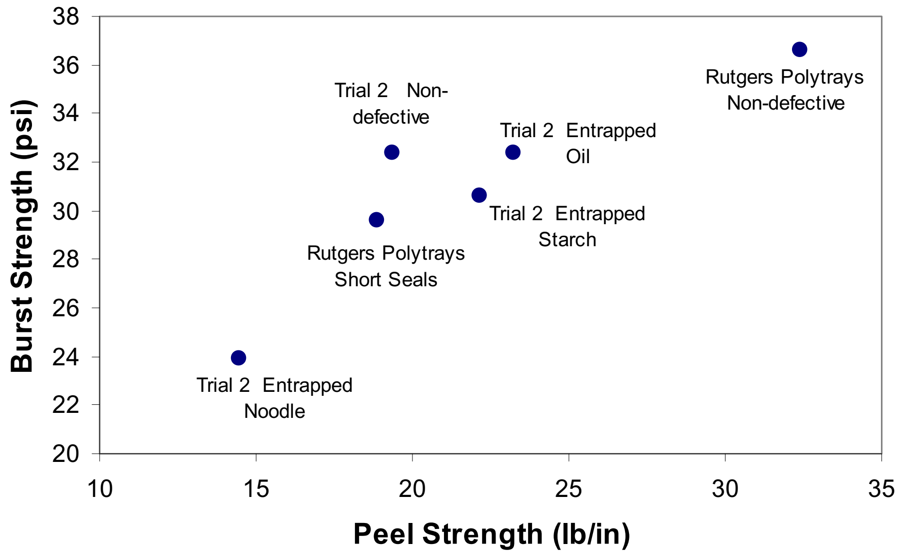

Figure 14. Correlation of burst versus peel strength of Rutgers and Trial 2 polytrays.

2.5 Microbial Challenge

The microbial challenge was done using a total of seventy-five polytrays with non-defective trays and artificial channel defects ranging from 50.8 to 381 μm. These polytrays were produced along with five control (no defects) samples during Trail 1 at Vendor 1. After the polytrays were retorted and transported to the Food Science & Technology department at the University of Tennessee, Knoxville, the wires were pulled from the seals and then the packages were dipped in the microorganism *Enterobacter aerogene*. The polytrays were exposed for 2 min at 21-25°C in the varying concentrations and then were placed in incubation, at an elevated temperature of 35°C. The concentrations were as follows: Chlorinated Water (negative control of 7-9 ppm FAC), 3 log colony formation units (CFU)/mL, and 6 log CFU/mL. Five positive control samples were post cool inoculated with the microorganism as well. Daily examination of the packages was conducted to check for gas formation or bacteria growth. Activity (swelling) was recorded as bacteria grow in the polytrays. Bacteria produce carbon dioxide (CO_2) gas as they grow and the polytray in turn swells.

The microbial challenge experiment was carried out to see if artificial defects such as channel defects would affect the seal integrity of the polytray when exposed to bacteria. The detailed results of the microbial challenge that was carried out at the Food Science & Technology department at the University of Tennessee, Knoxville can be seen in Appendix B. A (+) sign indicates gas formation from the growth of bacteria within the polytray. As gas forms within the polytray, the package becomes internally pressurized. Pressurized packages from gas formation can be seen in Figure 15.

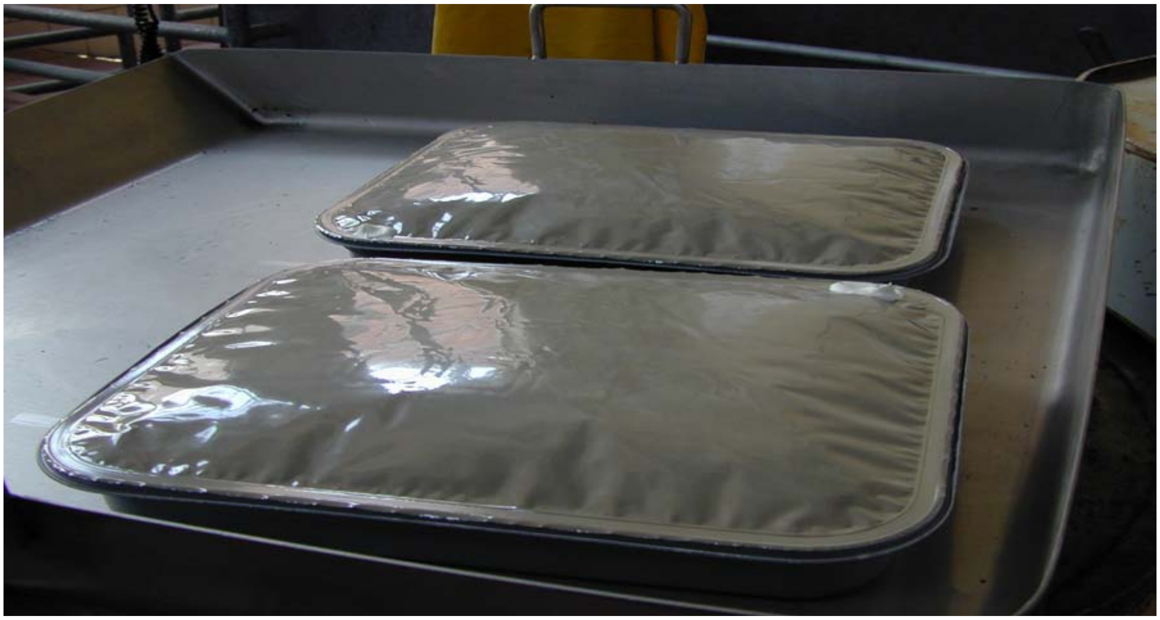

Figure 15. Photograph of pressurized polytray due to gas formation from bacteria growth.

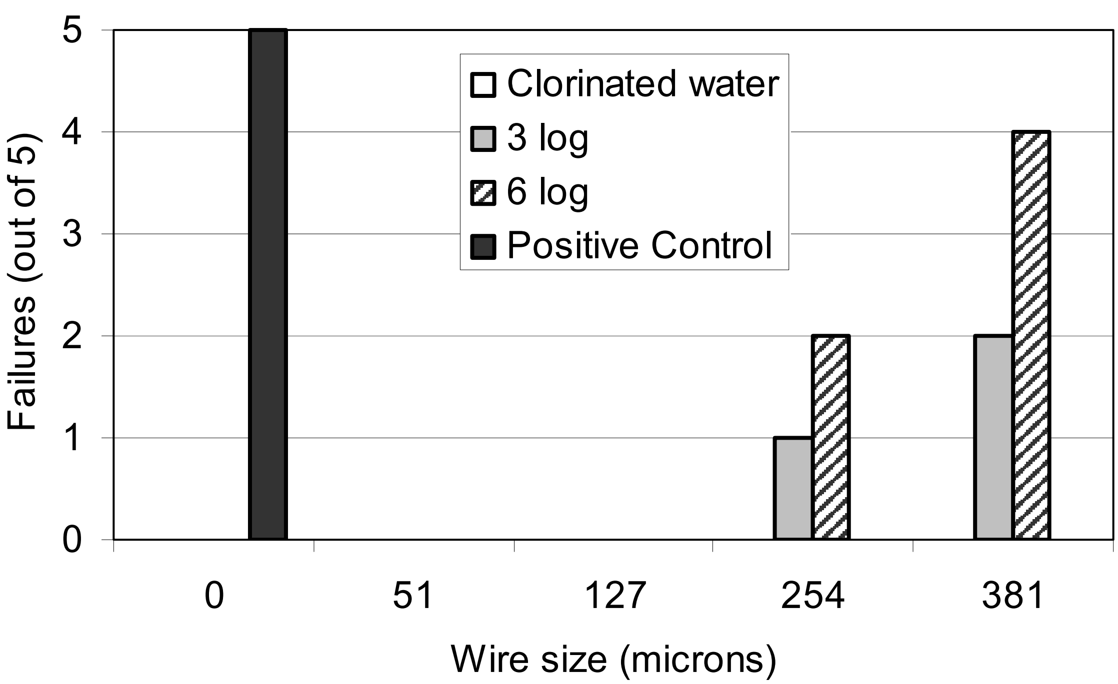

Figure 16. Microbial challenge results for polytrays produced in Trial 1. Chart shows number of trays that showed gas formation after 12 days incubation.

Figure 16 is a bar chart that displays the total number of polytrays that failed, or showed gas production (bacteria growth), after 12 days of incubation. Concentrations of the contaminated water (see Appendix B) are given as 3 log CFU/mL and 6 log CFU/mL; 10^3 and 10^6 microorganisms per 1 mL of water. Six out of fifteen polytrays with the 381 micron channel defect were positive (+) for CO_2 gas production. Three out of fifteen polytrays with the 254 micron defect were positive (+) for gas production. All five inoculated polytrays (positive control) were positive (+) for gas production. None of the other non-defective samples (0 micron wire) failed. Fifteen polytrays were also dipped into negative control, chlorinated water (10 ppm FAC), and none of these polytrays produced gas while in incubation. The most valuable result from this challenge was that none of the trays with the 50.8 and 127 μm channel defects failed.

The trays with channel defect less than or equal to 127 μm were obviously not as serious as the other channel defects. Note that the burst testing results above showed that the instrumented burst test can detect leaks from channel defects as small as 50 μm at pressures as small as 5 psi. Based on the accuracy of the digital flow meter used in the PC interfaced system, it is estimated that leaks from channel defects as small as 20 μm should be detectable under internal pressures of 25 psi.

2.6 Finite Element Stress Analysis

The finite element method can model a solid object such as the military polytray and subject that object to forces and pressures. Simulation of pressurization of a polytray was performed using FEMLAB® software. The results of these simulations can show the stresses that are present at any point within the object. Figure 17 shows a quartered polytray and the loading geometry for the corner forces applied to the quartered package. Modeling was done with the SolidWorks® program and was imported into the FEMLAB® software. Pressurized simulations were run at $2.0x10^4$, $5.0x10^4$, $1.0x10^5$, $1.5x10^5$, and $2.0x10^5$ Pa or 2.9, 7.25, 14.5, 21.8, and 29 psi. Corner forces were also simulated on the polytray at 50, 100, 150, and 200 N loads. Modulus values calculated from the tensile testing of the lid stock and tray were used as the input values for the simulations; $2.02x10^5$ psi and $2.66\ x10^5$ psi respectively. In order to reduce the simulation times, symmetry conditions were used; only one quarter of the polytray was used for the simulation.

Symmetry conditions within the FEMLAB® software can be utilized for simulation. Quartering the actual 3D model takes place in the SolidWorks® program before importing into the finite element analysis program. Since the polytray is symmetrical, it can be cut into sections and simulated as an entire polytray instead of simulating the entire polytray. This saves simulation time because the software requires a great deal of computer memory.

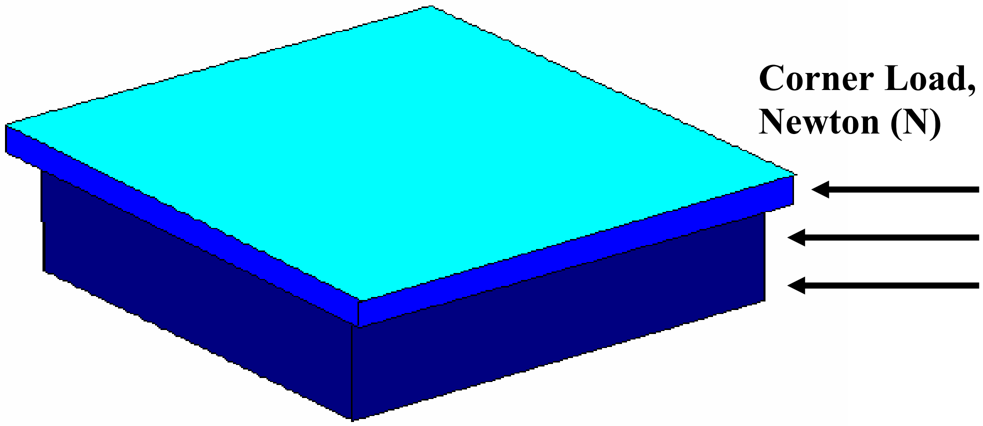

Figure 17. Quartered package showing the loading geometry for the corner loading.

The inside edge of the heal seal in a polytray can be treated as a crack. There are three modes of loading that a crack can experience; Mode I, II, and III. Mode I loading is seen as normal to the crack plane and will cause the seal to peel open. Mode II is due to the in-plane shear stress and will cause the lid to slide towards or away from the center of the polytray with respect to the tray flange. Mode III corresponds to out-of-plane shear, or tearing, and will cause the lid to slide along the length of the seal.

Figure 18 shows the modes of fractures as a schematic. A body can be loaded in any of these modes, or in any combination of these modes. In the case of the pressurization and corner load simulations we see all modes in combination. These modes of fracture can be separately analyzed using the FEMLAB® software.

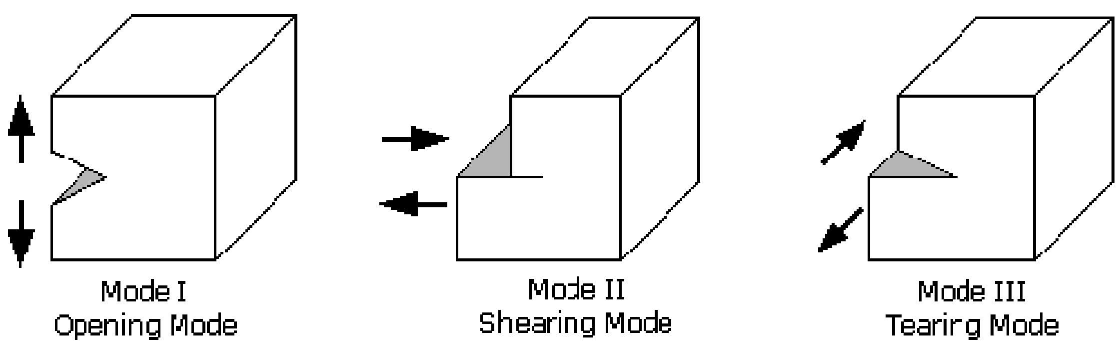

Figure 18. Schematic of the three modes of fracture.

The internal pressure simulations, which model the burst test, were run at 2.9, 7.3, 10.9, 14.5, 21.8, and 29.0 psi. Corner forces were also simulated on the model polytray. These simulate a tray that is dropped on a corner. Corner loads ranging from 2 to 45 lb (10 to 200 N) were simulated. Note that the maximum corner load is about 7 times the actual weight of a filled polytray. Figure 19 is the result from the simulations for a pressurization of a polytray at 2.9 psi. It represents the von Mises stresses and shows the deformed shape of the package as it is pressurized.

From these simulations, the maximum stresses which corresponded to each fracture mode (I, II, and III) were determined, and these can be seen in Table 2 and Figures 20 and 21. Modes I and II dominate in the pressurization simulations, while modes I and III dominate in the corner load simulations. Even though modes I and II dominate in the pressure simulations, it can be seen that all of the stresses (even mode III) in the these simulations are much higher (roughly by a factor or 1000) than the stresses in the corner load simulations. Therefore, it can be concluded that an internal pressure burst test adequately stresses the seal in all three modes and another test to specifically test the seal in shear (modes II or III) is not necessary.

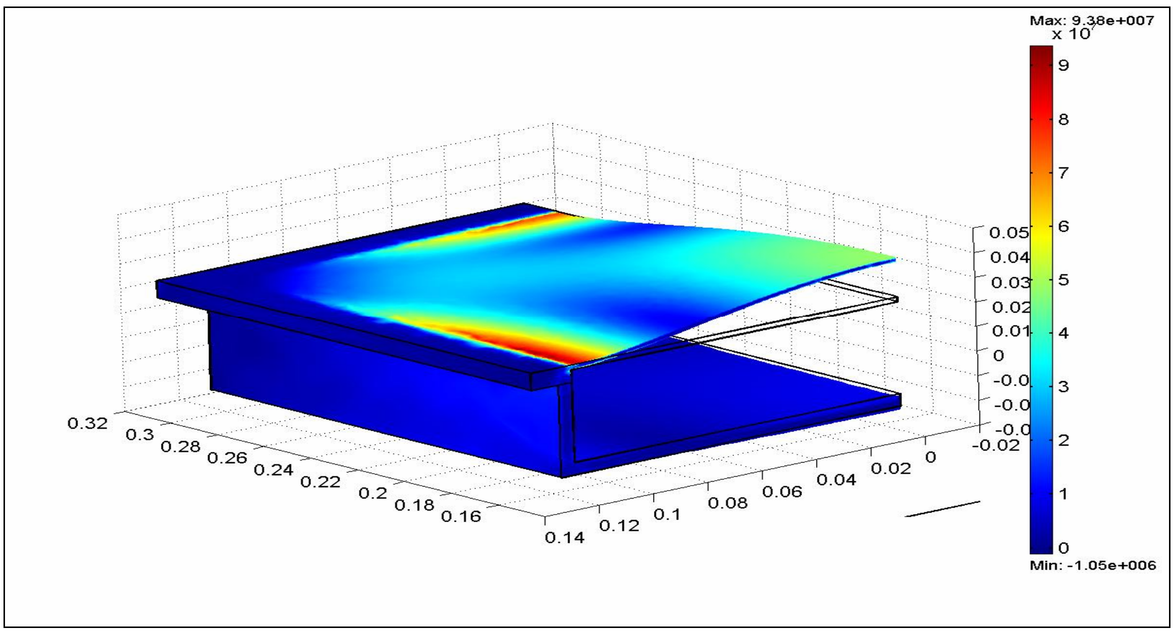

Figure 19. Von Mises stress pressure simulation of a quartered package run at 2.9 psi showing deformed shape.

Table 2. Maximum stresses (Mode I, II, and III) produced as a result of pressure and corner load simulations.

Pressure Simulations

Pressure (Pa)	**Pressure (psi)**	Mode I (Pa)	Mode II (Pa)	Mode III (Pa)
2.00E+04	2.9	2.70E+07	1.40E+07	2.0E+06
5.00E+04	7.3	6.70E+07	3.60E+07	5.0E+06
7.50E+04	11.0	1.00E+08	5.50E+07	7.5E+06
1.00E+05	14.5	1.30E+08	7.20E+07	1.0E+07
1.50E+05	21.8	2.00E+08	1.10E+08	1.5E+07
2.00E+05	29.0	2.70E+08	1.40E+08	2.0E+07

Corner Load Simulations

Load (N)	Mode I (Pa)	Mode II (Pa)	Mode III (Pa)
10	3.30E+03	2.0E+02	1.70E+03
50	3.60E+04	7.5E+02	6.70E+03
100	8.00E+04	1.3E+03	1.90E+04
150	1.20E+05	1.8E+05	3.50E+04
200	1.60E+05	2.5E+03	5.30E+04

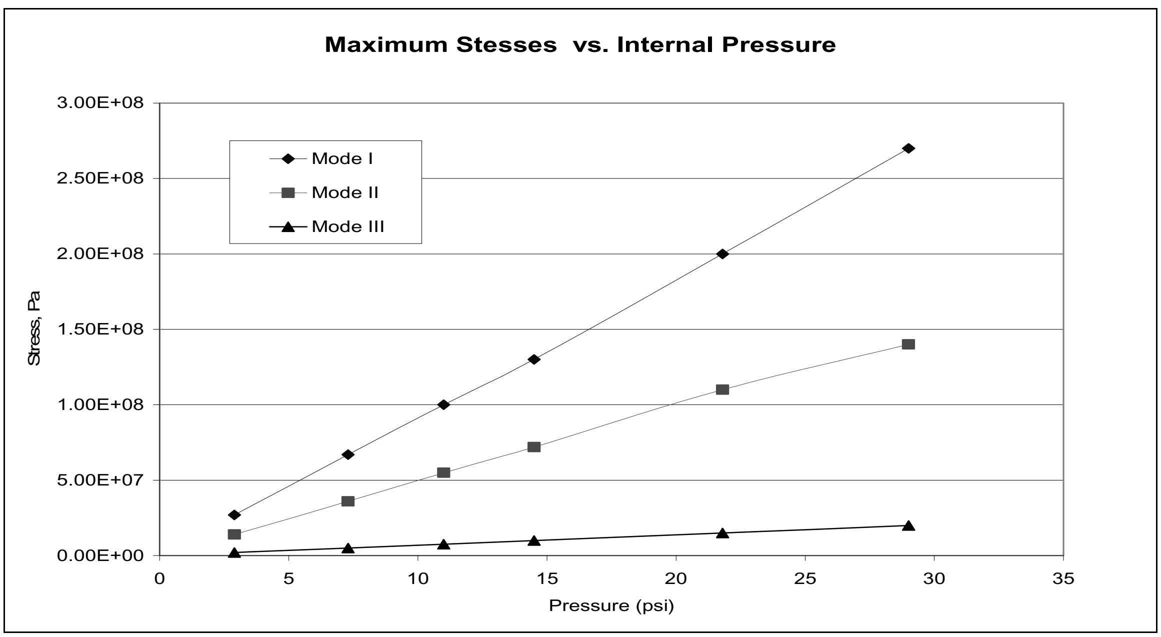

Figure 20. Plot of maximum stresses developed in burst simulation with increasing internal pressure.

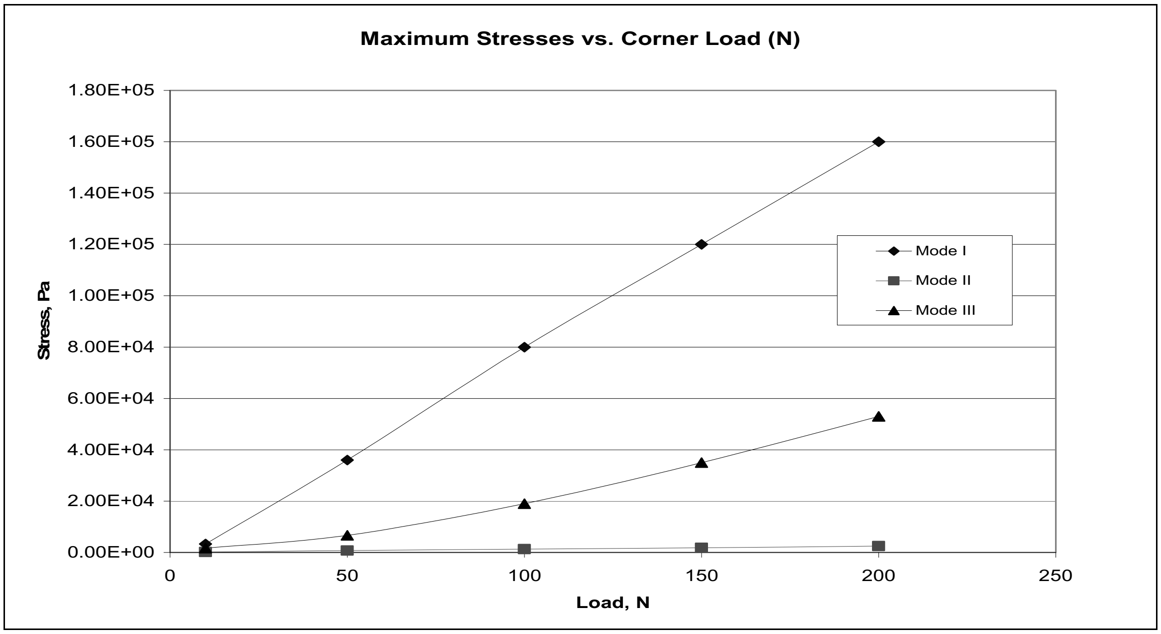

Figure 21. Plot of maximum stresses developed in corner load simulation with increasing load.

2.7 Non-contact Ultrasonic Inspection

Polytrays were sent to two potential subcontractors for a no-cost feasibility study of in-line non-contact ultrasonic inspection of polytrays. The potential subcontractors were Karta Technologies (San Antonio, TX) and PTI, LLC (Tuckahoe, NY) and inspections were performed on defect-free polytrays and those which contained entrapped starch (from Trial I) and multiple channel defects ranging from 50 to 381 microns. Karta's inspection was performed with their Lazound™ laser-based ultrasonic system. The resulting scans from defect-free seals and those with defects were not dramatically different. In addition, this system required 6 minutes to scan a package at 50 micron resolution. Based on these results, further exploration of this technology was not pursued.

PTI inspected the polytrays with their SEAL-SCAN ™ which utilizes non-contact, airborne ultrasonic inspection technology. This system was not able to detect the presence of defects in any of the samples inspected. They suggested that better results might be obtained using a transducer custom fabricated for polytrays. However, PTI supplied a $22,750 quote for the cost of developing such a transducer. Therefore, further exploration of this technology was not pursued, and the $29,500 direct cost (and associated indirect cost) originally budgeted for a more thorough feasibility analysis was not spent.

3 Phase II

3.1 Objectives

The main objectives of Phase II of this project were to 1) Prove the effectiveness of the instrumented burst test developed in Phase I, 2) Perform expanded burst testing on polytrays with specific seal defects to determine the exact extent to which they degrade seal integrity, and 3) Recommend a burst test protocol an acceptable tray should sustain without leaking or bursting.

Achievement of these objectives may have two important consequences. Certain polytray seal defects that pass the instrumented burst test may be reclassified as being less severe (*e.g.*, from major to minor). Also, if a number of visually defective polytrays seals from a single lot can pass the instrumented burst test, this may allow the lot to be declared acceptable. Either of these would lead to decreased lot rejections and increased manufacturing capacity.

3.2 Polytray Acquisition

Polytrays were received from Vendors 1 and 3 in December 2004. The food trays were visually inspected first and categorized according to defects in seal area. The military inspection guide [38] was followed throughout the classification process as a reference. Tables 3 and 4 show the classification of the received food trays:

Table 3. Categorization of defective and non-defective food trays from Vendor 1.

Defect	**Number of Trays**
Non-Defective	19
Delamination	11
Entrapped Matter	9
Blisters/ Air Bubbles	28
Damaged Trays	3
Tunneling	8
Short Seal	8
Total	**86**

Table 4. Categorization of defective and non-defective food trays from Vendor 3.

Defect	**Number of Trays**
Non-Defective	25
Short Seal	22
Entrapped Matter/ Moisture/ Air Bubbles	6
Multiple Defects (Short Seal + Wrinkles + Moisture)	8
Total	**61**

The following details were noted during categorization:

1. Product inside the tray
2. The dimensions of the defect; i.e. length of the short seal, the diameter of the air bubble, the width of the short seal,
3. The non-defective seal width
4. A rough sketch of the defective area of the seal

Some of the rough sketches of the defects are presented in Figure 22. It shows four different types of defects; short seal, uneven seal, entrapped matter and air bubble in the seal. According to the inspection guide, the seal width less than 5/16'' will be scored a short seal [12]. Entrapped matter or void in the seal will be scored a defective seal. The dimensions of the defect and defect-free seal width were noted. Figures 23 and 24 show blister and tunneling defects in the seal of the package respectively.

Figure 25 is the schematic sketch of a short seal package received from Vendor 3 with the width and length of the short seal. The sketch shows the approximate dimensions of the tray. The side of the tray in which the hole is drilled is referred as side 1 and other sides are numbered sequentially in clockwise manner. In this particular case, the length and width of the short seal are 7''and ¼'' respectively. Seal width across the corner is also noted in order to accurately categorize the tray. The exact descriptions of the defects and the corresponding burst pressures are collected in Appendix E.

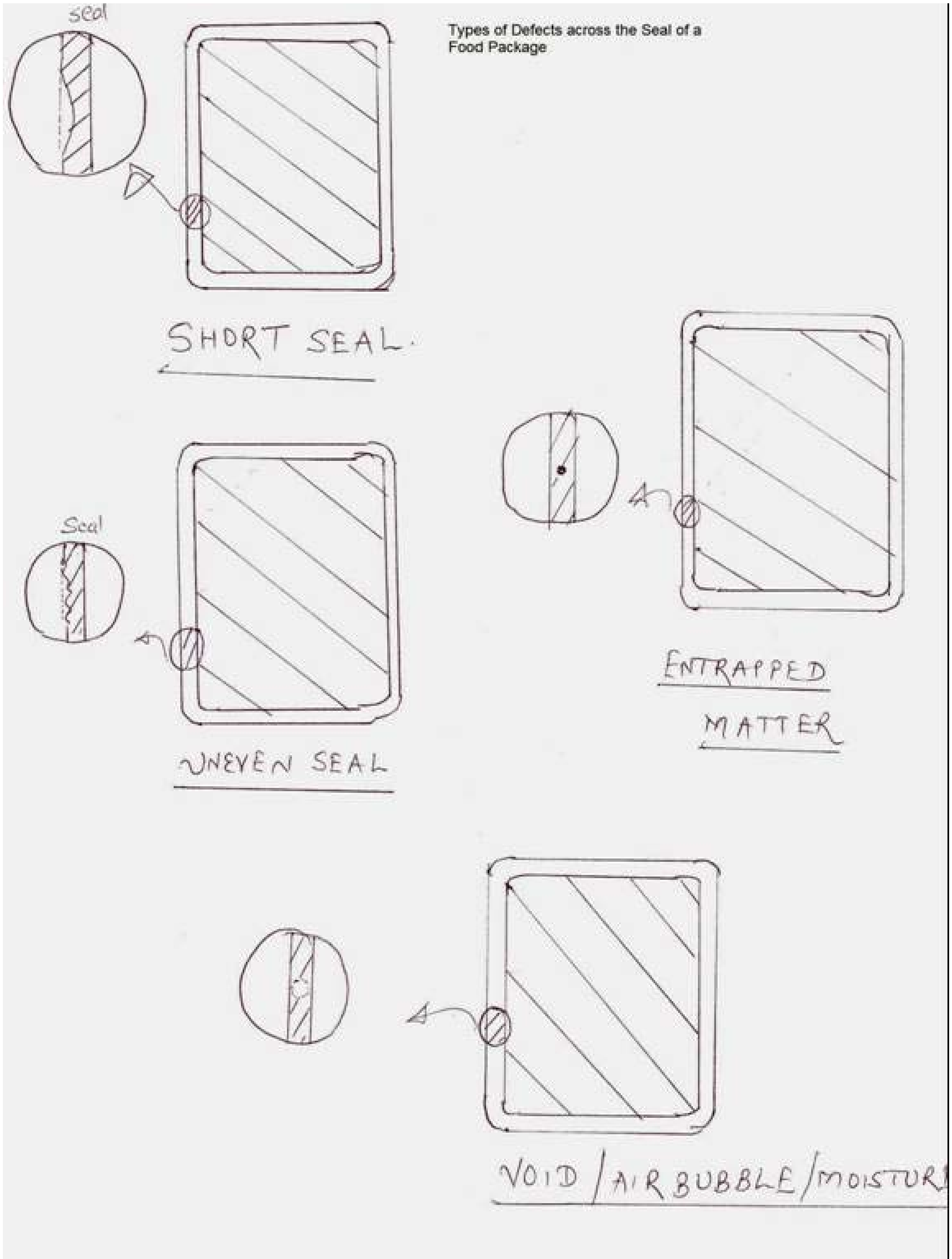

Figure 22. The schematic drawing of some of the defects in the seal

Figure 23. A blister in the seal of the food tray.

Figure 24. Tunneling defect in the seal of a food tray.

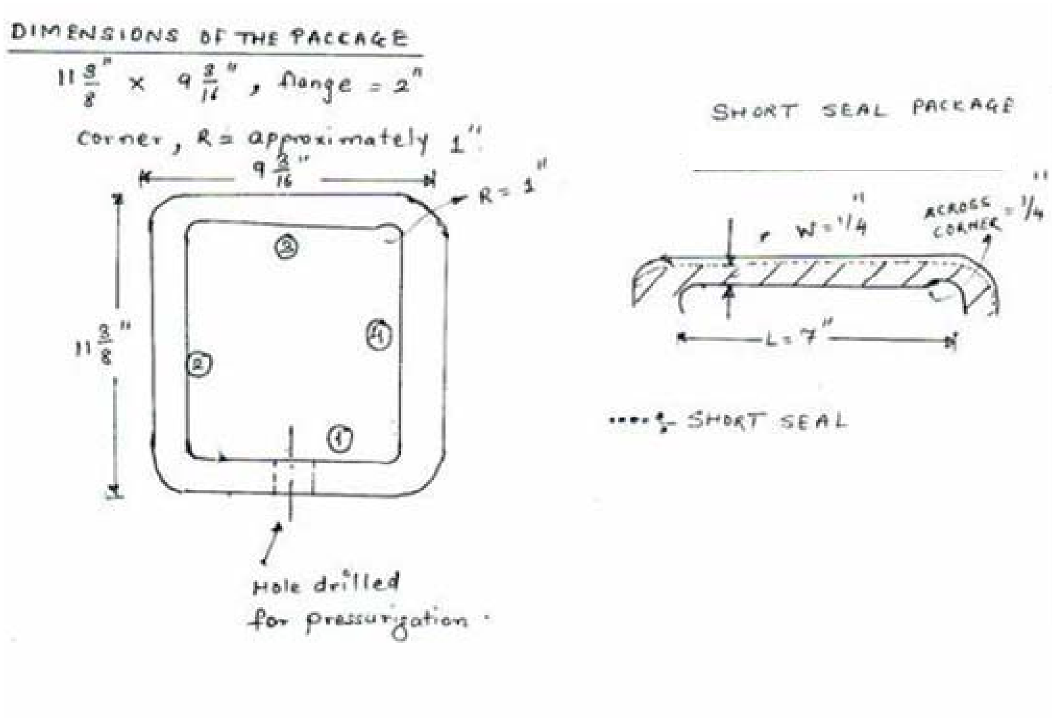

Figure 25. Schematic drawing of a defective tray with a short seal from Vendor 3.

3.3 Instrumented Burst Testing

The instrumented burst test developed in Phase I was used for all burst testing in Phase II. All pressure and flow rate data was saved automatically to a PC during each test. For all the experiments, the initial pressure was set to 10 psi. It would automatically increase by 5 psi every 5 minutes, thus allowing sufficient time for the system to stabilize and the flow rate to return to zero if there was no leak in the tray. When the pressure in the tray was increased, the flow rate into the tray would exceed the maximum possible measurable. The five minute delay between pressure steps was necessary to allow the flow meter to restabilize. The pressure at which the package failed was recorded for all the packages. The system recorded the pressure and flow rate data every 10 seconds.

All of the trays that were tested in Phase II had food inside them. It was initially decided that if the tray sustained pressure of 40 psi the test would be terminated. However, because of the pressure inside the package, the food would flow back and clog the entire tubing when the relief valve was opened. Quite often, the pressure was so high that the food would even enter the controller system. Cleaning of the system would then be very difficult and time consuming.

Therefore, it was decided that letting the tray pressurize to failure would be the best procedure. However, to maintain consistency with the earlier tests, whenever the tray burst at pressures above 40 psi, the recorded pressure for the purposes of average and comparing data would be 40 psi.

The test gave the pressures at which the trays leaked or burst; which could directly relate to whether the seal was strong. The pressure was measured for each food tray. The average burst pressure for each category of defective and non-defective trays was then calculated and used for statistical analysis of the data. At this point, it must be mentioned the basis on which the package was considered to leak. From the previous work, a standard for a leak and burst was set. A tray with air-flow of 0.4 cc/min would be considered to have developed a leak.

The consignment of food trays for this testing was received on December 3, 2004 from Vendors 1 and 3. Each and every tray was inspected for defects and categorized. The severity of defect was assigned based on the inspection guide provided and sketches were prepared showing the dimensions of defects and defect free length of the seal. The consignment received contained trays with the following defects; short seal, entrapped matter, blisters and air bubbles, delamination and tunneling. (Refer to Appendices D and E for specific information on individual defect descriptions and failure pressures.)

3.3.1 Burst Test Results

Tables 5 and 6 and Figure 26 show the average burst pressures of the received trays, with and without defects. The error bars seen on the data are based on standard deviation in burst pressure measured for each defect.

Table 5. Burst test results for the trays with various defects from Vendor 1.

Defect	Average Pressure (psi)	Max/Min Pressure (psi)	No of Trays Tested	Standard Deviation
Non- Defective	34.3	40/20	14	6.7
Short Seals	28.3	40/25	9	5.5
Blisters	23.1	30/15	27	3.7
Entrapped Matter	23.1	25/20	8	2.6
Tunneling	23.4	30/20	13	3.1

Table 6. Burst test results for the trays with various defects from Vendor 3.

Defect	Average Pressure (psi)	Max/Min Pressure (psi)	No of Trays Tested	Standard Deviation
Non- Defective	34.4	40/25	24	5.0
Short Seals	36.2	40/35	24	3.8
Blisters	35.0	40/35	5	3.5
Entrapped Matter	40.0	40/35	8	4.5

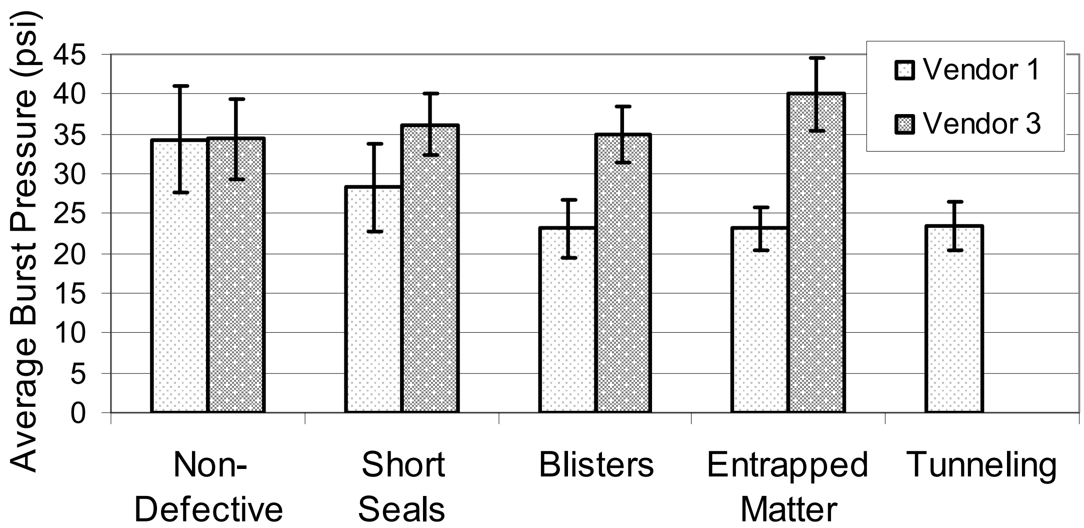

Figure 26. The average burst pressure of non-defective and defective packages.

It can be seen that the average burst pressure of the non-defective trays from Vendors 1 and 3 are almost the same. However, the defective trays from Vendor 3 sustained much higher burst pressures than those from Vendor 1. In fact, it seems that the defective packages from Vendor 3 performed as well as the non-defective ones. This is likely due to the nominally wider seals in the Vendor 3 trays. Non-defective trays from Vendor 3 had seal width close to 5/16", while those from Vendor 1 had seal width less than 4/16".

Figures 27 and 28 show the relative burst pressures of short seal packages from Vendor 1 and Vendor 3 with different seal widths. Non-defective packages from Vendor 1 showed higher burst pressures than the packages with 2/16" and 3/16" seal widths. There was not much difference in the burst pressure of the Vendor 3 short seal trays with seal widths of 3/16'' and 4/16'' compared to that of non-defective ones. This fact should be seen in the perspective that the short seal packages were far less in number than the non-defective ones, and those with 2/16'' seal width were just too few to generate a statistically significant average. There was just one tray from Vendor 3 with a seal width of 2/16'' and it sustained 40 psi.

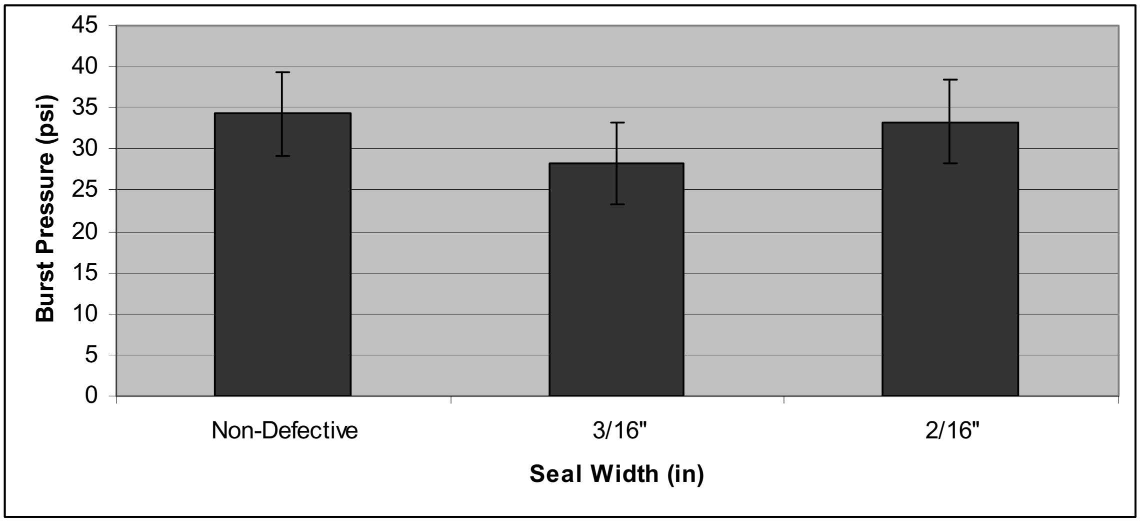

Figure 27. Burst Pressure of short seal trays from Vendor 1.

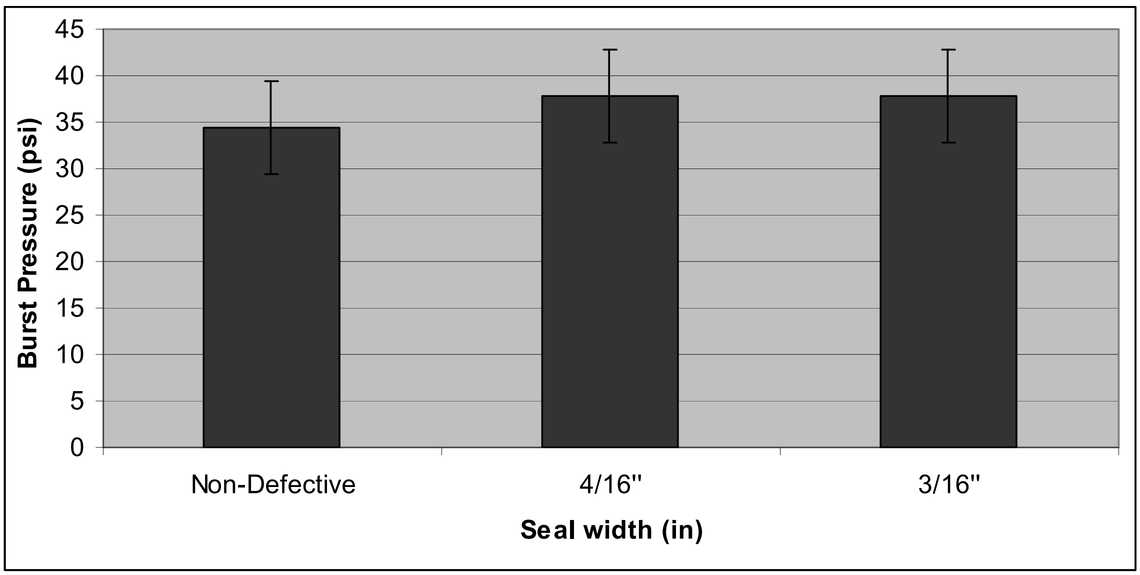

Figure 28. Burst Pressure of short seal trays from Vendor 3.

Figure 29 shows the percentage of trays, from Vendor 1 with no defects, blisters, entrapped matter, tunneling defects, delamination, and short seals that failed below a particular pressure level. It can be seen that the data for all of the defective trays except those with short seals performed similarly and in general failed at pressures much lower than the non-defective trays. The short seal trays from Vendor 1 performed in between the non-defective and other kinds of defective trays. When the data is presented in this format there seems to be a clear division between the seal strengths of defective and non-defective trays. This data will be used to make a recommendation for adopting a minimal burst pressure acceptance criterion.

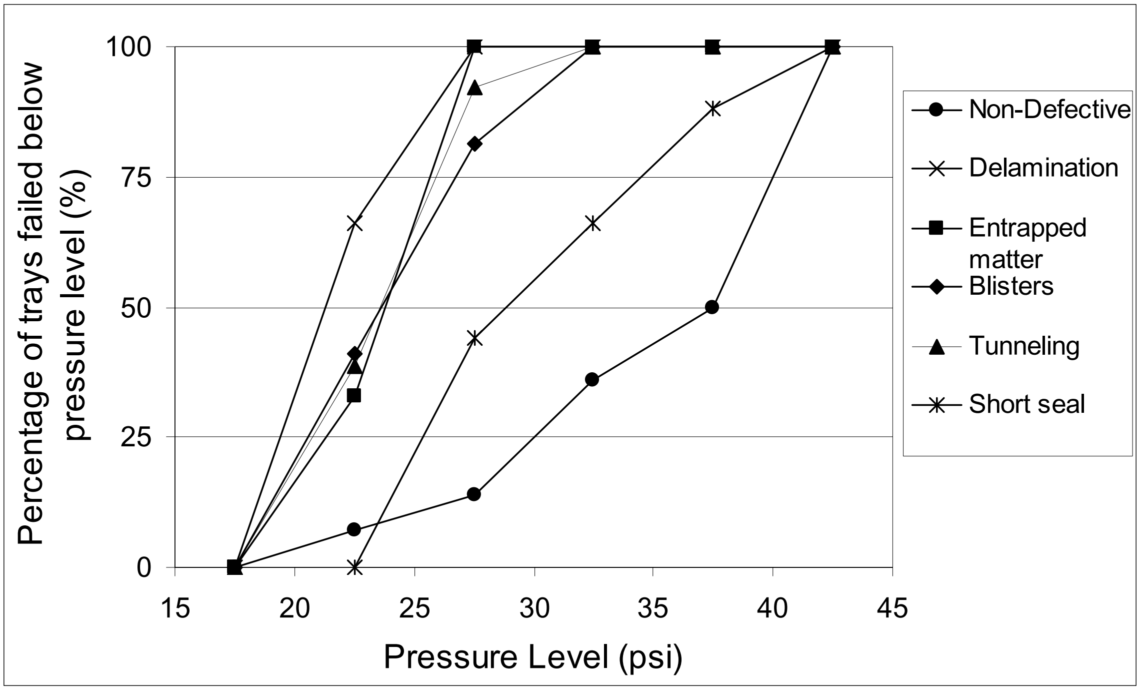

Figure 29. Percentage of Vendor 1 trays that failed below a certain pressure level.

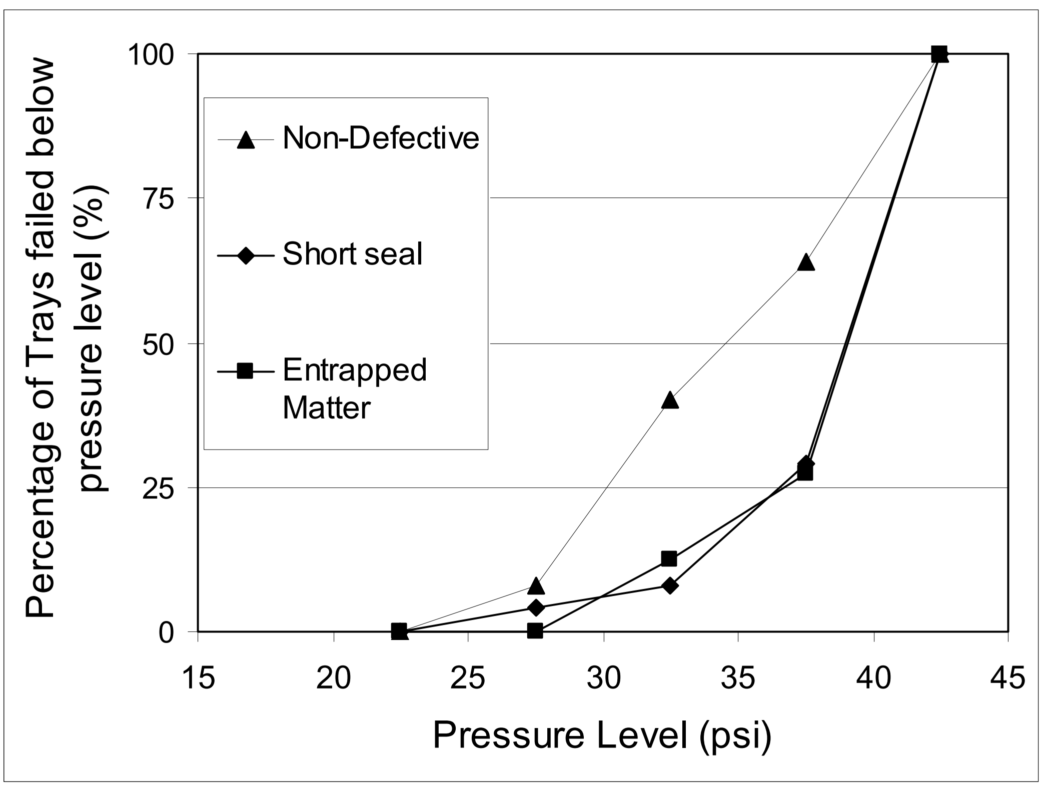

Figure 30. Percentage of Vendor 3 trays that failed below a certain pressure level.

Figure 30 shows the percentage of trays from Vendor 3 with no defects, entrapped matter, and short seals that failed below a particular pressure level. It can be seen that Vendor 3 trays with defects performed just as good or rather slightly better than non-defective trays. Based on this data, a rationalization can me made that polytrays with certain entrapped matter and short seal defects should have adequate seal strength.

In general, it can be observed that the burst pressure sustained by food trays manufactured by Vendor 3 is higher than that by trays manufactured by Vendor 1. The likely reason for the low burst pressures for defective seals from Vendor 1 is the narrower nominal seal width. The trays with tunneling defects were mostly seen to produce leaks at lower pressures; which is expected as the tunneling defect mainly represents a discontinuity in the seal. The items packed inside the polytrays might have some role to play as far as the seal strength is concerned, but the exact relation could not be established. Most of the food trays from Vendor 1 had chicken gravy and pepper in them; while those from Vendor 3 had mostly desserts.

3.4 Finite Element Simulations

Two dimensional simulations were done in order to understand the effect of the gap length between the polytray lid and the top of the burst chamber. Various simulations with varying distance between the lid and plate were performed and shear and normal stresses across the seal measured. Figure 31 shows the 2D model of the polytray used for these simulations.

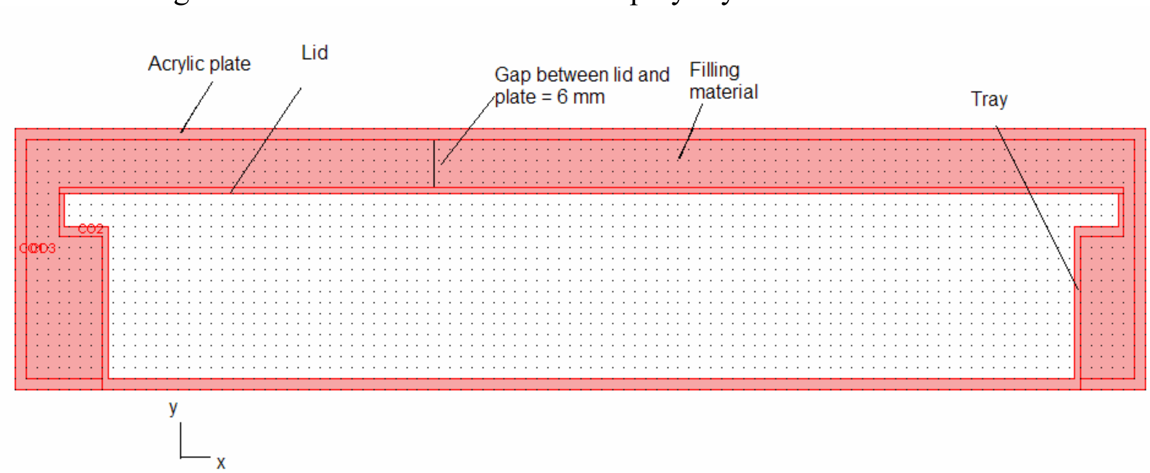

Figure 31. 2D drawing of the polytray in Femlab® with a filling material.

The gap between the acrylic plate and lid was varied between 3 and 38 mm. In the actual burst tests, the acrylic plate was reinforced with steel bar from top. Therefore, the modulus of acrylic plate was assumed to be 2E11 Pa and that of lid and tray (both being the polymeric materials) to be 1E09 Pa, based on results from Phase I. The pressure inside the tray was varied from 20,000 Pa (3 psi) to 180,000 Pa (27 psi).

The stress condition in the seal as a result of pressurization of the tray can be simulated using a suitable finite element analysis program like Femlab 3.0®. A series of simulations was performed with increasing pressure inside the tray from 20,000 Pa (3 psi) to 180,000 Pa (27 psi). The increase in maximum normal (mode I) and shear (mode II) stresses in the seal followed a linear relationship with the applied pressure as can be seen in Figure 32.

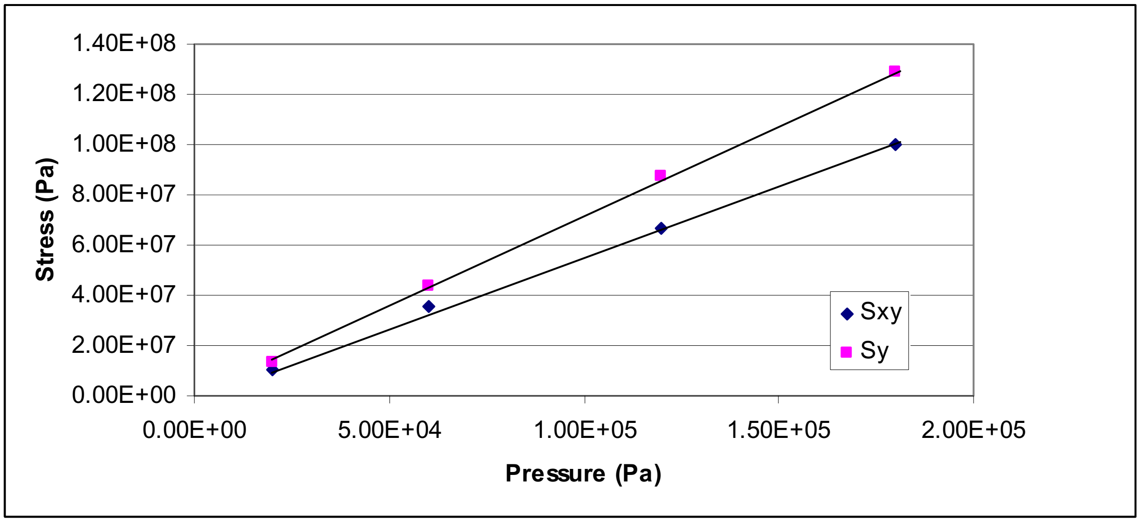

Figure 32. Increase in stresses with increase in pressure in the tray.

Another series of simulations were performed with increasing distance between the lid of the polytray and top plate of the burst chamber while the pressure was maintained at 3 psi. The current practice for the burst test in the industry involves pressure of 20 psi for 30 seconds, and the specified minimum separation distance is 3 mm. As shown in Figure 33, the simulations show that the burst tests that were carried out during this project were more severe than those in current practice since the gap between lid and the acrylic plate was 6 mm for the burst tests carried out during this project.

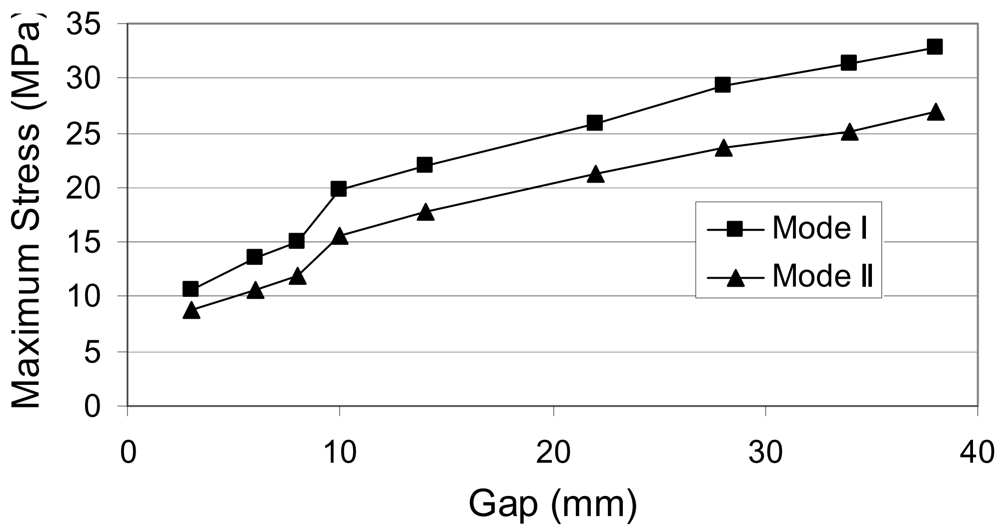

Figure 33. The maximum mode I and mode II stresses in the seal with increasing separation at 20,000 Pa.

3.5 Seal Failure Mechanism

When inspecting the lid material after a burst failure, it was observed that a delamination of the lid occurred in every instance. It is reasonable to assume that failure of the seal will initiate between the PP layers in the tray and lid which were fused together during the sealing process. The evidence of delamination suggests that at some point during failure of the seal the fracture path jumps to another layer in the lid material such as the polyester/nylon layer. Such a proposed failure path is demonstrated in Figure 34.

In order to determine the exact failure path that was followed, scanning electron microscopy (SEM) and Fourier Transform Infrared (FTIR) spectroscopy was performed on the lid failure surfaces. SEM analysis was done on several seals from the burst food trays. The piece of lid previously sealed to the tray was cut from the side which burst open. All of the samples had two distinctly different regions separated by a clear boundary. The dimensions of the samples were such to fit on the aluminum stub in the SEM; typically about 8 mm x 5 mm. A typical micrograph of the boundary area is shown in Figure 35. Energy Dispersive Spectroscopy (EDS) was performed in the SEM and indicated that the layer on the right hand side of Figure 35 did not contain oxygen or nitrogen. It can therefore be concluded that this surface is a PP surface. EDS also showed the presence of either oxygen or nitrogen in the layer on the left hand side of Figure 35. This indicates that this layer could be nylon or polyester, but not PP.

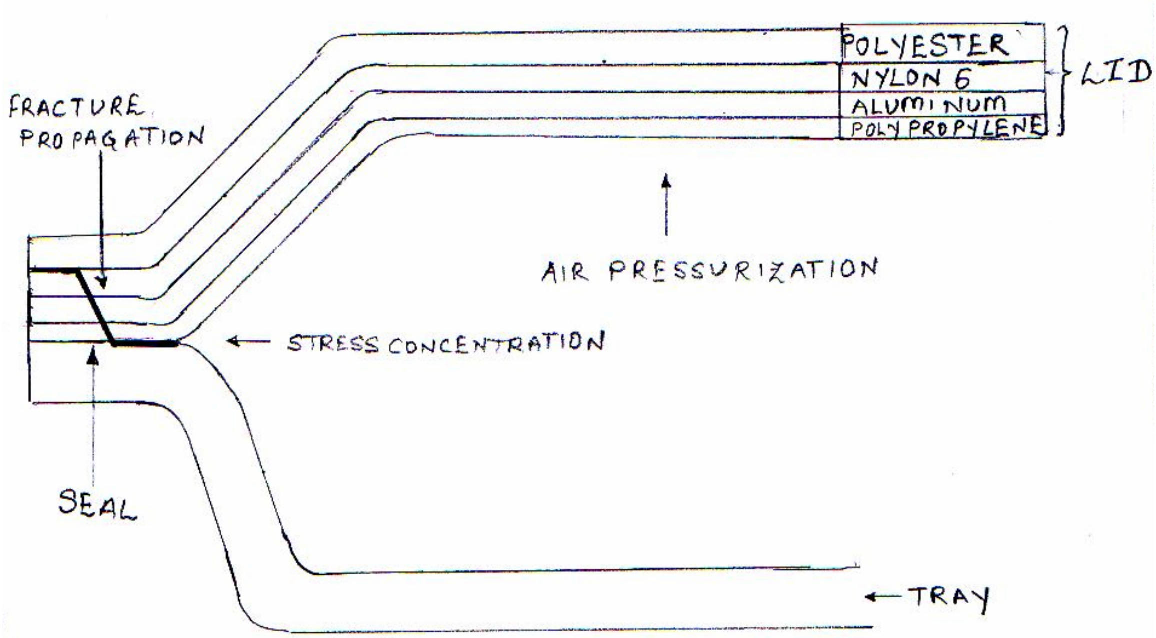

Figure 34. Schematic diagram showing the stress concentration and process of delamination.

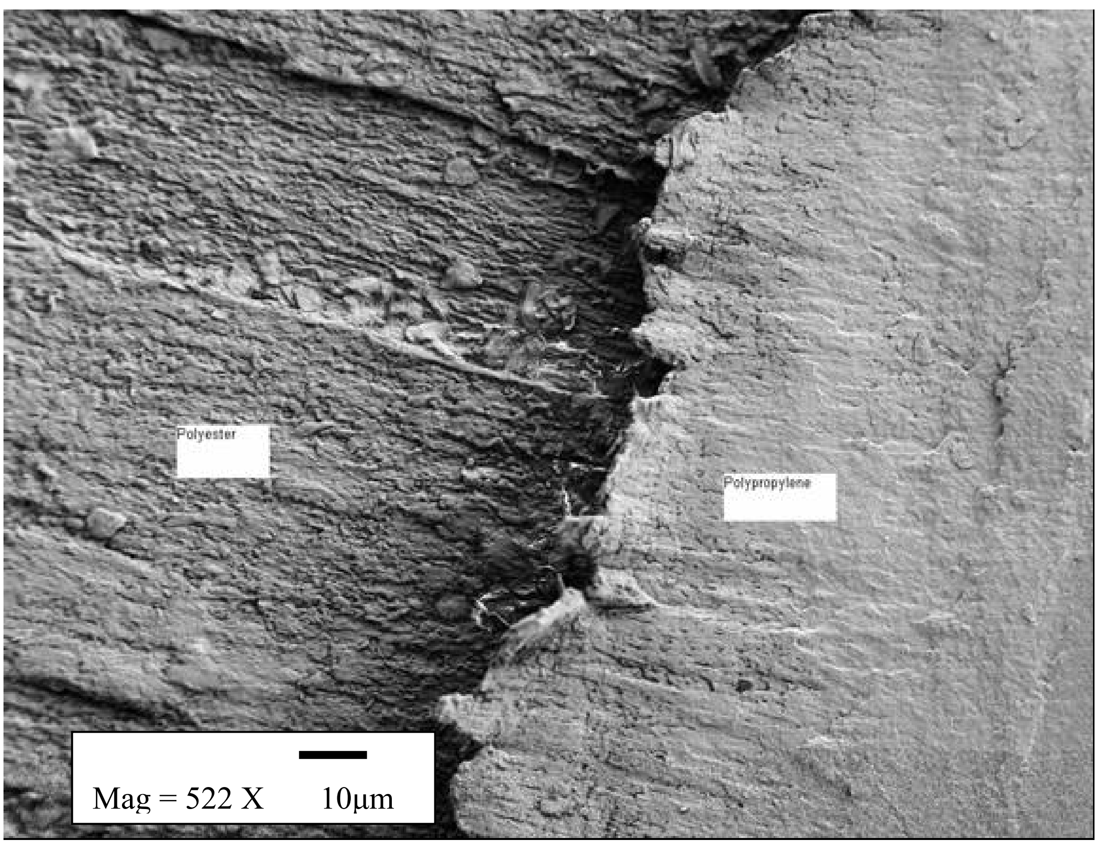

Figure 35. SEM image of the sample showing the fracture at PP/ polyester junction.

In order to determine whether the layer O/N containing layer was in fact nylon or polyester, FTIR spectroscopy using the Attenuated Total Reflectance method was performed on the same samples. Figure 36 shows the FTIR spectrum from the right half of Figure 35 along with a PP spectrum from the BioRad database. The similarities between the spectra confirm that this layer is in fact PP. Figure 37 shows the FTIR spectrum from the left half of Figure 35 along with a PET polyester spectrum from the BioRad database. The similarities between the spectra confirm that this layer is in fact PET polyester. Therefore, it can be concluded that the fracture path jumps from the initial PP/PP heat seal bond to the nylon/PET bond during a burst failure. Improving the adhesive strength of this bond or the tear strength of the nylon layer by the lidstock manufacturers may prevent this failure mechanism and increase the burst strengths of the polytrays.

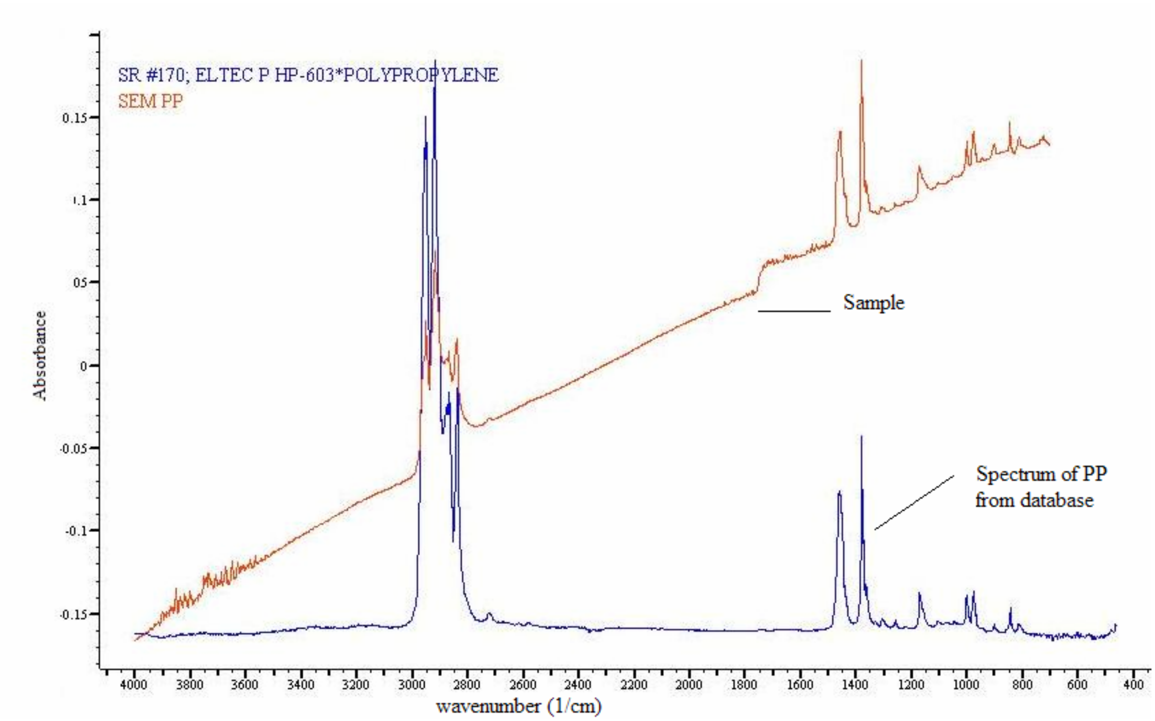

Figure 36. The spectrum obtained from PP layer of the sample used for the SEM analysis. The spectrum from the sample is compared with that from the BioRad database.

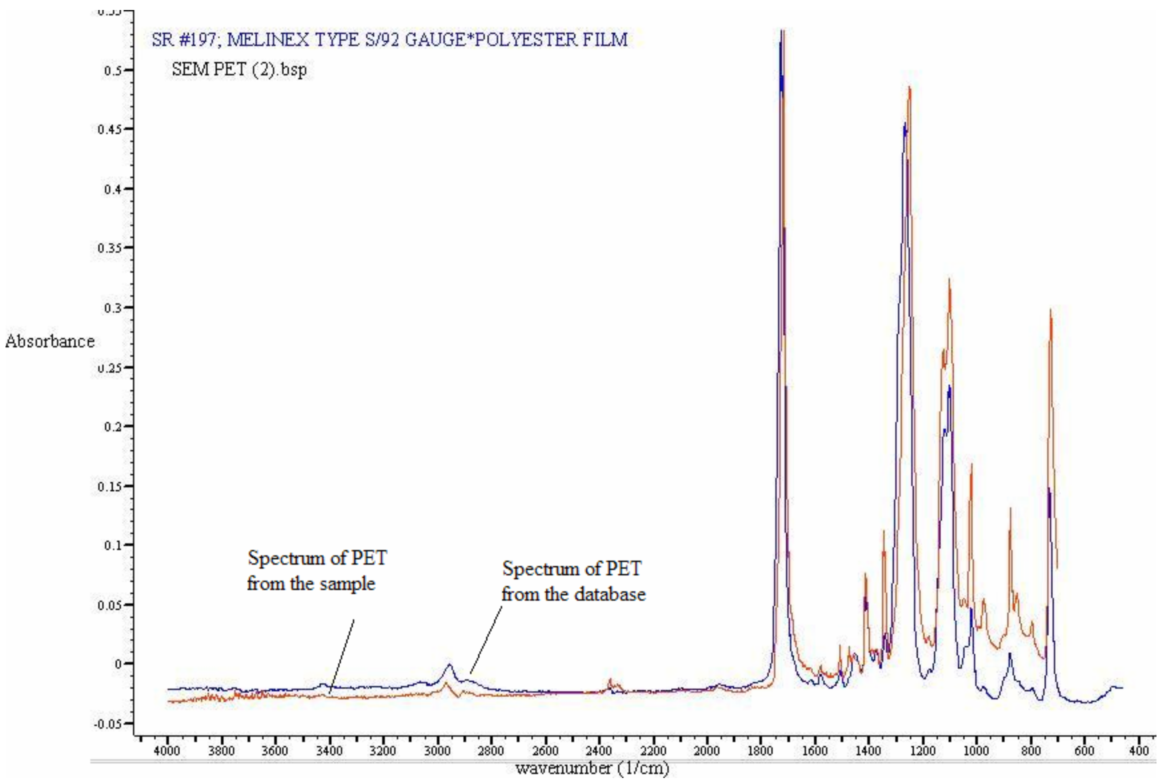

Figure 37. The spectrum obtained from polyester layer of the sample used for the SEM.

4 Conclusions and Recommendations

4.1 Conclusions

4.1.1 Burst Test

The instrumented burst test is capable of determining the precise internal pressure level at which a polytray package develops a small leak or explosively bursts. The smallest channel leak produced in Trial 1 was easily detectable at a pressure of 5 psi. Based on the minimum detectable flow rate (0.2 cc/min), channel leaks as small as 20 microns should be detectable at an internal pressure of 25 psi. The total cost of fabricating a this burst tester is approximately $5,000.

For the Trial 1 samples which included weak seals and entrapped matter (starch, oil, and noodle), burst test results correlated well with peel strengths. Burst test results exhibited less variance than peel test results.

In Trial 2, it was found that entrapped starch and oil in the seal did not reduce seal strength compared to defect-free seal while entrapped noodle in the seal resulted in a significant reduction in average burst strength.

In Phase II, it was found that non-defective seals from Vendors 1 and 3 performed very similarly. Short seals from Vendor 1 showed a slight decrease in seal strength compared to non-defective seals while other defects (entrapped matter, blisters, etc.) from Vendor 1 showed a large decrease in seal strength. This behavior was attributed to the smaller nominal seal width in polytrays produced by Vendor 1 (as compared to Vendor 3).

Polytrays from Vendor 3 with short seal and entrapped matter defects showed no decrease in seal strength compared to non-defective seals.

4.1.2 Finite Element Modeling

During a burst test, the seal primarily experiences Mode I peel stresses but also experiences significant Mode II shear stresses. It is concluded that an internal pressure burst test adequately stresses the seal in all three modes and another test to specifically test the seal in shear (modes II or III) is not necessary.

The stresses experienced by the seal during a burst test are dependent on the size of the gap between the top of the polytray and the bottom of the burst chamber restraining plate. An increase in gap size from 0.125 inch to 0.25 inch results in a 26% increase in stress levels. An increase in gap size from 0.25 inch to 1.0 inch results in a 104 % increase in stress levels.

4.1.3 Non-contact Ultrasonic Inspection

The methods studied (airborne and laser-based) were either too slow or too insensitive to be feasible for 100% online inspection of polytrays.

4.1.4 Seal Failure Mechanism

Seal failure as a result of the burst test initiates in the interior of the package at the heat seal formed between the polypropylene layers in the lid and tray. However, the failure path always migrated to polyester/nylon bond in quad layer lid film before final failure of the seal.

4.2 Recommendations

Based on the results obtained in this project and the conclusions stated above, the following recommendations are made:

4.2.1 The instrumented burst test should be used to test polytrays with certain visual seal defects that result in failure of a lot. If such polytrays pass the screening protocol listed below, the lot should also pass.

Burst Test Screening Protocol

- Pressurize to 5 psi to check for system leaks
- Increase pressure immediately to 25 psi
- Tray passes if no leak or burst after 5 minutes

4.2.2 The instrumented burst test should be used to evaluate the effect of common seal defects (in addition to those reported here) on actual seal strength. The methodology used for these tests should follow that described in section 2.4.2.

4.2.3 The instrumented burst test should be refined to provide:

a) improved venting for trays that do not leak or burst during test
b) a faster and simpler method for connecting the air hose to the tray
c) a better operator interface for the computer program that controls the tester
d) identification of a different flow meter that would allow for faster testing
e) a procedure to calibrate the pressure and flow rate sensors

4.2.4 An interface should be developed to allow the instrumented burst tester to be used with MRE packages.

4.2.5 Future polytray vendors should invest in sealing equipment similar to that used by Vendor 3.

4.2.6 A request should be made to quad film vendors to improve the polyester/nylon bond in these films and/or to improve the tear resistance of the nylon layer.

4.3 Instrumented Burst Tester Design

The components used in the assembly of the instrumented burst tester are listed in Table 7. A schematic showing plumbing and electrical connections is shown in Figure 38. The components are connected to the NI-DAQ data acquisition card *via* a National Instruments connector block and shielded cable. The NI-DAQ card is installed in a Windows PC and is utilized for the following:

Send

- DC signal to regulator to control pressure
- 5 VDC digital signal to control relay that switches solenoid valve
- constant 10 VDC to power pressure sensor

Receive

- DC signal from regulator to verify pressure
- DC signal from flow meter
- DC signal from pressure sensor

The total cost of the items listed in Table 7 is $2,182. Additional costs will be associated with assembly of these components, fabrication of the burst chamber, and use of a Windows computer. The details of the burst chamber design are given in Appendix C. The burst tester will be controlled by an executable program supplied at no cost by Kevin Kit and developed using LabVIEW 7.0. It is estimated that the total cost of fabricating a duplicate burst tester is approximately $5,000.

Table 7. Components used in instrumented burst test. Costs as of December 2003.

Item	Cost	Manufacturer
Servo Pressure Regulator 0-100 PSI	$215	Bellofram
FMA-A2101 Electronic Mass Flow meter	$494	Omega
PX302-200GV General Purpose Pressure Sensor	$185	Omega
SV251 Three-way Solenoid Valve	$112	Omega
SSR330DC25 Solid State Relay	$26	Omega
PCI-6036E Multifunction I/O & NI-DAQ	$745	National Instruments
SHC68-68-EP Shielded Cable, 2 m	$110	National Instruments
SCB-68 I/O Connector Block	$295	National Instruments

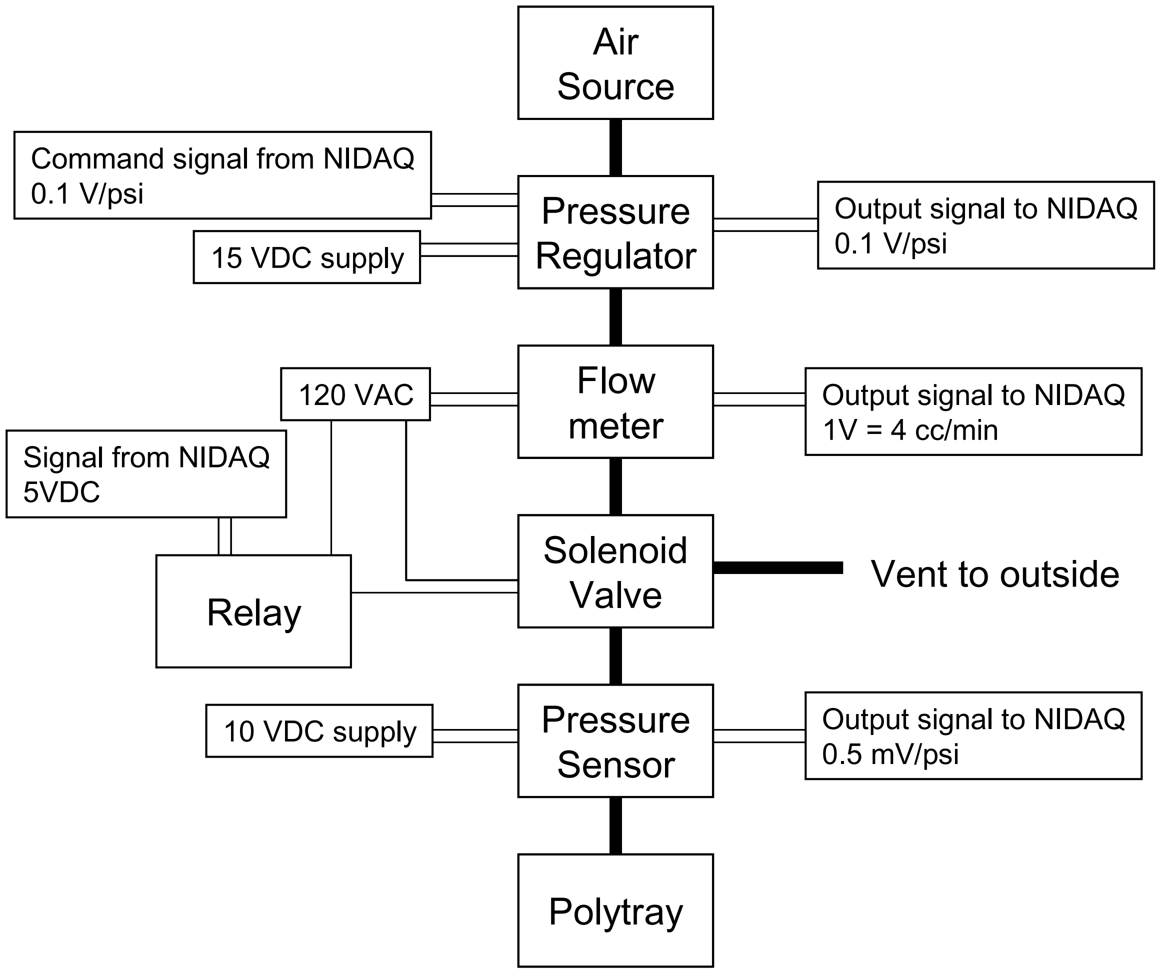

Figure 38. Schematic of instrumented burst test connections. Thick lines denote air lines. Thin lines denote electrical connections.

Appendix A: Tray Production and Retort Conditions

Table A.1: Empty polytray production with varying channel defects: Trial 1 6/5/2003.

Empty MRE Packages (E): 50 total						
Destructive/Mechanical Testing						
Sample	**Wire (μm)**	**Time (put in production)**		**Sample**	**Wire (μm)**	**Time (put in production)**
E1-0	0.0	4:55		E6-50.8	50.8	6:00
E2-0	0.0	4:55		E7-50.8	50.8	6:00
E3-0	0.0	4:55		E8-50.8	50.8	6:00
E4-0	0.0	4:55		E9-50.8	50.8	6:00
E5-0	0.0	4:55		E10-50.8	50.8	6:00
E6-0	0.0	4:55		E1-127	127.0	6:00
E7-0	0.0	4:55		E2-127	127.0	6:00
E8-0	0.0	4:55		E3-127	127.0	6:00
E9-0	0.0	4:55		E4-127	127.0	6:00
E10-0	0.0	4:55		E5-127	127.0	6:00
E1-254	254.0	5:15		E6-127	127.0	6:00
E2-254	254.0	5:15		E7-127	127.0	6:00
E3-254	254.0	5:15		E8-127	127.0	6:00
E4-254	254.0	5:15		E9-127	127.0	6:00
E5-254	254.0	5:15		E10-127	127.0	6:00
E6-254	254.0	5:15		E1-381	381.0	5:15
E7-254	254.0	5:15		E2-381	381.0	5:15
E8-254	254.0	5:15		E3-381	381.0	5:15
E9-254	254.0	5:15		E4-381	381.0	5:15
E10-254	254.0	5:15		E5-381	381.0	5:15
E1-50.8	50.8	6:00		E6-381	381.0	5:15
E2-50.8	50.8	6:00		E7-381	381.0	5:15
E3-50.8	50.8	6:00		E8-381	381.0	5:15
E4-50.8	50.8	6:00		E9-381	381.0	5:15
E5-50.8	50.8	6:00		E10-381	381.0	5:15

Table A2: Media filled polytray production with various channel defects: Trial 1 6/5/2003.

Media Filled Packages (MF): 80 total						
Microbial Challenge						
Chlorinated Water (10 ppm FAC)				**Contaminated Water (3 log CFU/ml)**		
Sample	**Wire (μm)**	**Time (put in production)**		**Sample**	**Wire (μm)**	**Time (put in production)**
MF1-0-Cl	0	11:05		MF1-0-3 log	0	11:40
MF2-0-Cl	0	11:05		MF2-0-3 log	0	11:40
MF3-0-Cl	0	11:05		MF3-0-3 log	0	11:40
MF4-0-Cl	0	11:05		MF4-0-3 log	0	11:40
MF5-0-Cl	0	11:05		MF5-0-3 log	0	11:40
MF1-254-Cl	254	12:40		MF1-254-3 log	254	1:05
MF2-254-Cl	254	12:40		MF2-254-3 log	254	1:05
MF3-254-Cl	254	12:40		MF3-254-3 log	254	1:05
MF4-254-Cl	254	12:40		MF4-254-3 log	254	1:05
MF5-254-Cl	254	12:40		MF5-254-3 log	254	1:05
MF1-50.8-Cl	50.8	2:30		MF1-50.8-3 log	50.8	2:55
MF2-50.8-Cl	50.8	2:30		MF2-50.8-3 log	50.8	2:55
MF3-50.8-Cl	50.8	2:30		MF3-50.8-3 log	50.8	2:55
MF4-50.8-Cl	50.8	2:30		MF4-50.8-3 log	50.8	2:55
MF5-50.8-Cl	50.8	2:30		MF5-50.8-3 log	50.8	2:55
MF1-127-Cl	127	2:00		MF1-127-3 log	127	2:00
MF2-127-Cl	127	2:00		MF2-127-3 log	127	2:00
MF3-127-Cl	127	2:00		MF3-127-3 log	127	2:00
MF4-127-Cl	127	2:00		MF4-127-3 log	127	2:00
MF5-127-Cl	127	2:00		MF5-127-3 log	127	2:00
MF1-381-Cl	381	11:05		MF1-381-3 log	381	11:40
MF2-381-Cl	381	11:05		MF2-381-3 log	381	11:40
MF3-381-Cl	381	11:05		MF3-381-3 log	381	11:40
MF4-381-Cl	381	11:05		MF4-381-3 log	381	11:40
MF5-381-Cl	381	11:05		MF5-381-3 log	381	11:40

Table A2: Continued.

Contaminated Water (6 log CFU/ml)		
Sample	**Wire (μm)**	**Time (put in production)**
MF1-0-6 log	0	12:30
MF2-0-6 log	0	12:30
MF3-0-6 log	0	12:30
MF4-0-6 log	0	12:30
MF5-0-6 log	0	12:30
MF1-254-6 log	254	1:05
MF2-254-6 log	254	1:05
MF3-254-6 log	254	1:05
MF4-254-6 log	254	1:05
MF5-254-6 log	254	1:05
MF1-50.8-6 log	50.8	2:55
MF2-50.8-6 log	50.8	2:55
MF3-50.8-6 log	50.8	2:55
MF4-50.8-6 log	50.8	2:55
MF5-50.8-6 log	50.8	2:55
MF1-127-6 log	127	2:00
MF2-127-6 log	127	2:00
MF3-127-6 log	127	2:00
MF4-127-6 log	127	2:00
MF5-127-6 log	127	2:00
MF1-381-6 log	381	12:30
MF2-381-6 log	381	12:30
MF3-381-6 log	381	12:30
MF4-381-6 log	381	12:30
MF5-381-6 log	381	12:30

Positive Control (post cool inoculated)		
Sample	**Wire (μm)**	**Time (put in production)**
MF1-0-PCI	0	11:55
MF2-0-PCI	0	11:55
MF3-0-PCI	0	11:55
MF4-0-PCI	0	11:55
MF5-0-PCI	0	11:55

Table A.3: Retort process conditions for Trial 1.

ICON 2000 Sterilization Report

Preheat					
	Time	Process Vessel Temp (F)	System Pressure (psi)	Water Level (%)	Flow (gal/min)
Step Begin	3:04:44	98.3	0.4	23	0
Step End	3:11:23	110	4.9	27	0
Total Time in Step	0:06:39				

Come Up					
	Time	Process Vessel Temp (F)	System Pressure (psi)	Water Level (%)	Flow (gal/min)
Step Begin	3:11:23	110	4.9	27	0
Step End	3:18:35	201.2	15.1	19	1100
Total Time in Step	0:07:12				

Come Up					
	Time	Process Vessel Temp (F)	System Pressure (psi)	Water Level (%)	Flow (gal/min)
Step Begin	3:18:35	201.2	15.1	19	1100
Step End	3:24:35	256	34.2	21	1357
Total Time in Step	0:06:00				

Come Up					
	Time	Process Vessel Temp (F)	System Pressure (psi)	Water Level (%)	Flow (gal/min)
Step Begin	3:24:35	256	34.2	21	1357
Step End	3:28:05	255.6	34.2	20	1354
Total Time in Step	0:03:30				

Cook					
	Time	Process Vessel Temp (F)	System Pressure (psi)	Water Level (%)	Flow (gal/min)
Step Begin	3:28:05	255.6	34.2	20	1354
Step End	4:55:10	252.9	34.1	20	1371
Total Time in Step	1:27:05				

Table A3: Continued

Micro Cool					
	Time	Process Vessel Temp (F)	System Pressure (psi)	Water Level (%)	Flow (gal/min)
Step Begin	4:55:10	252.9	34.1	20	1371
Step End	4:57:26	237	33.9	20	1355
Total Time in Step	0:02:16				
Cool					
	Time	Process Vessel Temp (F)	System Pressure (psi)	Water Level (%)	Flow (gal/min)
Step Begin	4:57:26	237	33.9	20	1355
Step End	5:02:26	193.8	34.9	21	1236
Total Time in Step	0:05:00				
Cool					
	Time	Process Vessel Temp (F)	System Pressure (psi)	Water Level (%)	Flow (gal/min)
Step Begin	5:02:26	193.8	34.9	21	1236
Step End	5:08:26	125.4	30	20	1338
Total Time in Step	0:06:00				
Cool					
	Time	Process Vessel Temp (F)	System Pressure (psi)	Water Level (%)	Flow (gal/min)
Step Begin	5:08:26	125.4	30	20	1338
Step End	2:28:26	79.4	15.1	21	1353
Total Time in Step	1:20:00				

Appendix B: Microbial Challenge Results and Microorganism Preparation

Sample (polytrays and microorganism) preparations for microbial challenge 1:

Polytray Preparation

Chlorinated Water (10 ppm FAC)		
	Test Samples – 4 wire sizes X 5 polytrays	20 samples
	Non-defective Samples	5 samples
Contaminated Water (3 log CFU/mL)		
	Test Samples – 4 wire sizes X 5 polytrays	20 samples
	Non-defective Samples	5 samples
Contaminated Water (6 log CFU/mL)		
	Test Samples – 4 wire sizes X 5 polytrays	20 samples
	Non-defective Samples	5 samples
Positive Control (post cool inoculated)		5 samples
Total Polytrays		80

Microorganism Washes

1. Prepare Cultures of *Enterobacter aerogenes*
   a. 5 tubes (10 mL each) in trypticase soy broth + starch
   b. Incubate 24 hr. at 37C
   c. Check for Gas formation (CO2)
2. Wash and rinse 3-5 gallon buckets with chlorinated water
3. Fill and add sodium thiosulfate to 2 of the buckets
4. Add 10 ppm (mg/L) sodium hypochlorite to the third bucket:
   a. Clorox or Purex (5,25% sodium hypochlorite)
   b. Needed 10 mg/L for 18.9 L = 0.189 mg
   c. Add 3.6 mL (0.0525 mg) of 5.25% Clorox or Purex in 5 gallons of water
5. High initial number – 6 log CFU/mL
   a. Add two tubes (20 mL) of *Enterobacter aerogenes* culture to 5 gallons of water with sodium thiosulfate
   b. Ca. 9 log CFU/Ml X 20 mL = $2x10^{10}$ CFU
   c. $2x10^{10}$ CFU/18,925 ml = 1.06×10^6 CFU/mL
6. Low initial number – 3 log CFU/mL
   a. Add 100 mL from high initial number *Enterobacter aerogenes* bucket to 5 gallon water with thiosulfate
   b. 1.06×10^8 CFU/18,925 mL – 5.6×10^3 CFU/mL
7. Dip all retorted polytrays for 2 minutes and agitate manually
8. For positive controls, add 1.0 mL of culture into a non-defective polytray

Table B.1: Results of Microbial Challenge 1 of Trial 1 Polytrays.

SAMPLE NO.	WIRE	DAY										
		1	2	3	4	5	6	7	8	9	10	11
Chlorinated Water (7-9 ppm FAC)												
MF1-0-CI	0	-	-	-	-	-	-	-	-	-	-	-
MF2-0-CI	0	-	-	-	-	-	-	-	-	-	-	-
MF3-0-CI	0	-	-	-	-	-	-	-	-	-	-	-
MF4-0-CI	0	-	-	-	-	-	-	-	-	-	-	-
MF5-0-CI	0	-	-	-	-	-	-	-	-	-	-	-
MF1-254-CI	254	-	-	-	-	-	-	-	-	-	-	-
MF2-254-CI	254	-	-	-	-	-	-	-	-	-	-	-
MF3-254-CI	254	-	-	-	-	-	-	-	-	-	-	-
MF4-254-Cl	254	-	-	-	-	-	-	-	-	-	-	-
MF5-254-CI	254	-	-	-	-	-	-	-	-	-	-	-
MF1-50.8-CI	50.8	-	-	-	-	-	-	-	-	-	-	-
MF2-50.8-CI	50.8	-	-	-	-	-	-	-	-	-	-	-
MF3-50.8-CI	50.8	-	-	-	-	-	-	-	-	-	-	-
MF4-50.8-CI	50.8	-	-	-	-	-	-	-	-	-	-	-
MF5-50.8-CI	50.8	-	-	-	-	-	-	-	-	-	-	-
MF1-127-CI	127	-	-	-	-	-	-	-	-	-	-	-
MF2-127-CI	127	-	-	-	-	-	-	-	-	-	-	-
MF3-127-CI	127	-	-	-	-	-	-	-	-	-	-	-
MF4-127-CI	127	-	-	-	-	-	-	-	-	-	-	-
MF5-127-CI	127	-	-	-	-	-	-	-	-	-	-	-
MF1-381-CI	381	-	-	-	-	-	-	-	-	-	-	-
MF2-381-CI	381	-	-	-	-	-	-	-	-	-	-	-
MF3-381-CI	381	-	-	-	-	-	-	-	-	-	-	-
MF4-381-CI	381	-	-	-	-	-	-	-	-	-	-	-
MF5-381-CI	381	-	-	-	-	-	-	-	-	-	-	-
3 log CFU/ml												
MF1-0-3 log	0	-	-	-	-	-	-	-	-	-	-	-
MF2-0-3 log	0	-	-	-	-	-	-	-	-	-	-	-
MF3-0-3 log	0	-	-	-	-	-	-	-	-	-	-	-
MF4-0-3 log	0	-	-	-	-	-	-	-	-	-	-	-
MF5-0-3 log	0	Lost										
MF1-254-3 log	254	-	+									
MF2-254-3 log	254	-	-	-	-	-	-	-	-	-	-	-
MF3-254-3 log	254	-	-	-	-	-	-	-	-	-	-	-
MF4-254-3 log	254	-	-	-	-	-	-	-	-	-	-	-
MF5-254-3 log	254	-	-	-	-	-	-	-	-	-	-	-
MF1-50.8-3 log	50.8	-	-	-	-	-	-	-	-	-	-	-
MF2-50.8-3 log	50.8	-	-	-	-	-	-	-	-	-	-	-

Table B.1: Continued

SAMPLE NO.	WIRE	DAY										
		1	2	3	4	5	6	7	8	9	10	11
MF3-50.8-3 log	50.8	-	-	-	-	-	-	-	-	-	-	-
MF4-50.8-3 log	50.8	-	-	-	-	-	-	-	-	-	-	-
MF5-50.8-3 log	50.8	-	-	-	-	-	-	-	-	-	-	-
MF1-127-3 log	127	-	-	-	-	-	-	-	-	-	-	-
MF2-127-3 log	127	-	-	-	-	-	-	-	-	-	-	-
MF3-127-3 log	127	-	-	-	-	-	-	-	-	-	-	-
MF4-127-3 log	127	-	-	-	-	-	-	-	-	-	-	-
MF5-127-3 log	127	-	-	-	-	-	-	-	-	-	-	-
MF1-381-3 log	381	-	-	-	-	-	-	-	-	-	-	-
MF2-381-3 log	381	-	+									
MF3-381-3 log	381	-	+									
MF4-381-3 log	381	-	-	-	-	-	-	-	-	-	-	-
MF5-381-3 log	381	-	-	-	-	-	-	-	-	-	-	-
6 log CFU/ml												
MF1-0-6 log	0	-	-	-	-	-	-	-	-	-	-	-
MF2-0-6 log	0	-	-	-	-	-	-	-	-	-	-	-
MF3-0-6 log	0	-	-	-	-	-	-	-	-	-	-	-
MF4-0-6 log	0	-	-	-	-	-	-	-	-	-	-	-
MF5-0-6 log	0	-	-	-	-	-	-	-	-	-	-	-
MF1-254-6 log	254	-	-	-	-	-	-	-	-	-	-	-
MF2-254-6 log	254	-	-	-	-	-	-	-	-	-	-	-
MF3-254-6 log	254	-	-	+								
MF4-254-6 log	254	-	-	+								
MF5-254-6 log	254	-	-	-	-	-	-	-	-	-	-	-
MF1-50.8-6 log	50.8	-	-	-	-	-	-	-	-	-	-	-
MF2-50.8-6 log	50.8	-	-	-	-	-	-	-	-	-	-	-
MF3-50.8-6 log	50.8	-	-	-	-	-	-	-	-	-	-	-
MF4-50.8-6 log	50.8	-	-	-	-	-	-	-	-	-	-	-
MF5-50.8-6 log	50.8	-	-	-	-	-	-	-	-	-	-	-
MF1-127-6 log	127	-	-	-	-	-	-	-	-	-	-	-
MF2-127-6 log	127	-	-	-	-	-	-	-	-	-	-	-
MF3-127-6 log	127	-	-	-	-	-	-	-	-	-	-	-
MF4-127-6 log	127	-	-	-	-	-	-	-	-	-	-	-
MF5-127-6 log	127	-	-	-	-	-	-	-	-	-	-	-
MF1-381-6 log	381	-	+									
MF2-381-6 log	381	-	-	-	-	-	-	-	-	-	-	-
MF3-381-6 log	381	-	+									
MF4-381-6 log	381	-	+									
MF5-381-6 log	381	-	+									

Table B.1: Continued

SAMPLE NO.	WIRE	DAY										
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Positive Control (Inoculated)												
MF1-0-PCI	0	+										
MF2-0-PCI	0	+										
MF3-0-PCI	0	+										
MF4-0-PCI	0	+										
MF5-0-PCI	0	+										

Appendix C: Design of Burst Chamber

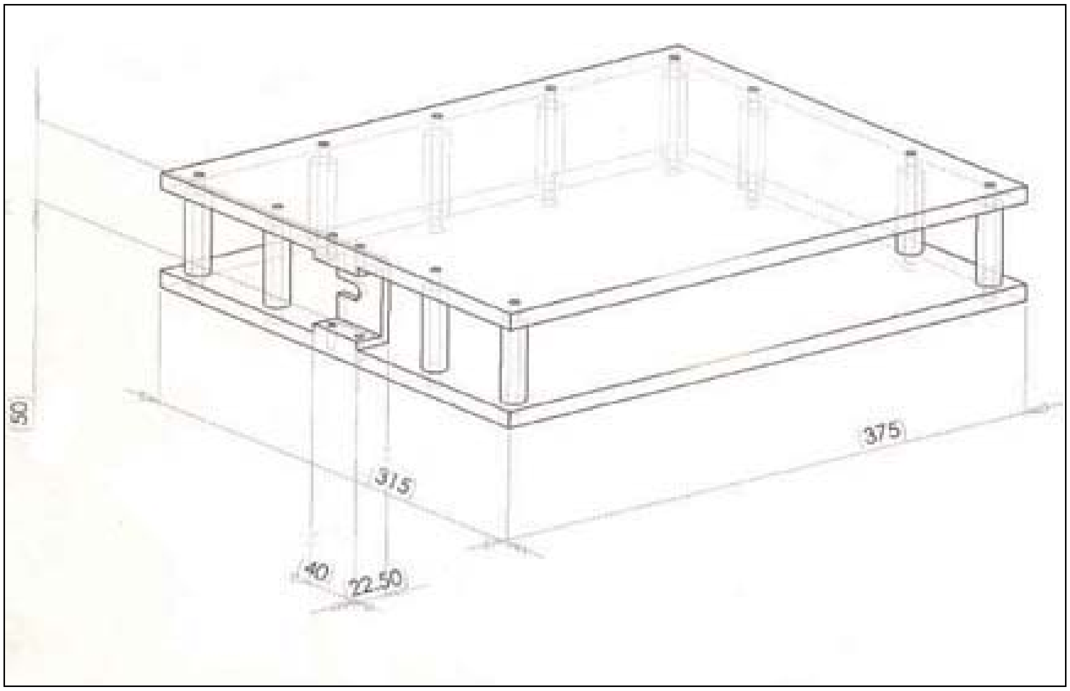

Figure C.1: SolidWorks® drawing of a burst chamber: isometric view.

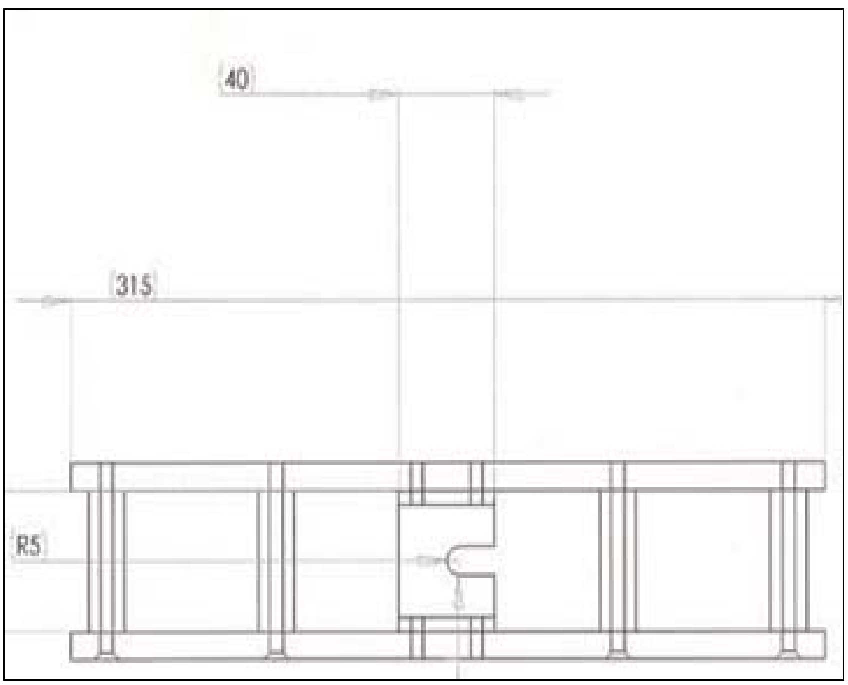

Figure C.2: SolidWorks® drawing of a burst chamber: side view.

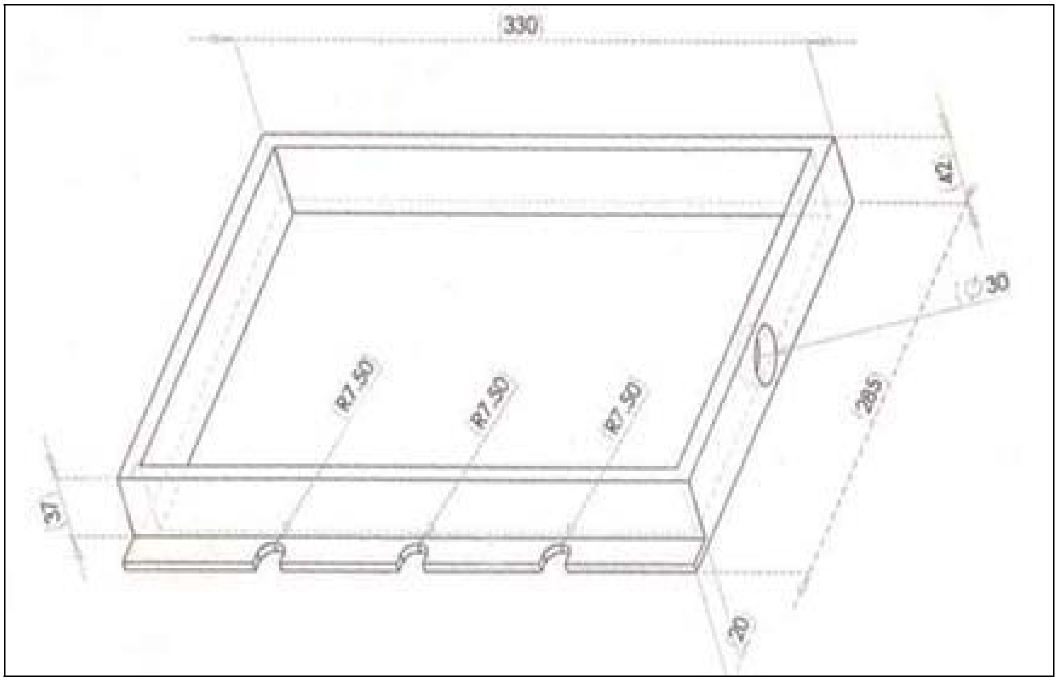

Figure C.3: SolidWorks® drawing of a burst tray insert: isometric view.

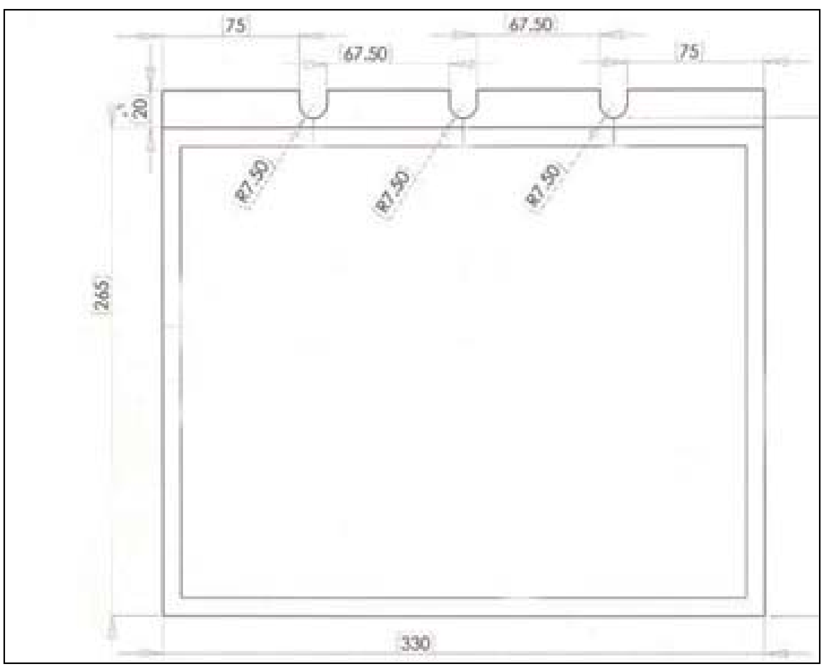

Figure C.4: SolidWorks® drawing of a burst tray insert: top view.

Appendix D: Classification of Non-Defective Food Trays (Phase II)

Table D.1: Non-defective trays from Vendor 3.

Sample Number	Food	Pressure (psi)	Comment
1.1	Blue Berry Desert	40	Smooth flow, test terminated
1.2	Blue Berry Desert	25	Burst early
1.3	Blue Berry Desert	35	Developed leak at 35 psi
1.4	Blue Berry Desert	40	Smooth flow rate
2.1	Mashed Potatoes	40	Test terminated
2.2	Mashed Potatoes	30	Leaked at 30 psi
2.3	Mashed Potatoes	30	Leaked
2.4	Mashed Potatoes	35	Leaked
3.1	Apple Dessert	35	Developed later leaked
3.2	Apple Dessert	30	Smooth flow, later leaked
3.3	Apple Dessert	40	Test terminated
3.4	Apple Dessert	30	Leaked
4.1	Apple Dessert	30	Developed leak at 30 psi
4.2	Apple Dessert	30	Leaked, erratic flow
4.3	Apple Dessert	40	Test terminated
4.4	Apple Dessert	40	Test terminated
5.1	Apple Dessert	25	Developed early leak
5.2	Apple Dessert	40	Smooth flow, test terminated
5.3	Apple Dessert	35	Smooth flow, then leaked
5.4	Apple Dessert	35	Smooth flow, then leaked
5.5	Apple Dessert	40	Smooth flow, test terminated
6.1	Black Berry Dessert	30	Increasing flow rate, leaked
6.2	Black Berry Dessert	35	Developed leak at 35 psi
6.3	Black Berry Dessert	30	Increasing flow rate
6.4	Black Berry Dessert	40	Smooth flow, test terminated

Table D.2: Non-defective trays from Vendor 1.

Sample Number	**Food**	**Pressure (psi)**	**Comment**
1.1	Chicken Breast	20	Early leak
1.2	Chicken Breast	40	Smooth flow, test terminated
1.3	Chicken Breast	40	Smooth flow, test terminated
1.4	Chicken Breast	30	Developed a leak at 30 psi
1.5	Chicken Breast	25	Early leak, burst at 25 psi
2.1	Chicken Breast	40	Smooth flow, test terminated
2.2	Chicken Breast	30	Smooth flow, then burst
2.3	Chicken Breast	35	Burst
2.4	Chicken Breast	40	Smooth flow, test terminated
3.1	Chicken Breast	30	Leaked
3.2	Chicken Breast	40	Test terminated
3.3	Chicken Breast	40	Smooth flow, test terminated
3.4	Chicken Breast	30	Burst
3.5	Chicken Breast	40	Smooth terminated

Appendix E: Classification of Defective Food Trays (Phase II)

Table E.1: Defective trays with blisters in the seal from Vendor 1. The table contains the description of defects and corresponding burst pressure.

Sample No	Pressure (psi) and Comment
1.1	25,Two blisters, critical L = 1/8'', size = 1/16''
1.2	30, Imperfections on the seal at the corner, a tunneling defect, L = 1/8''
1.3	20, On the corner and on the inner edge
1.4	20, L = 4'', lot of blisters, very small in size, some on the inner edge.
2.1	25, L = 4½'' small blisters, critical on the inner edge; tunneling defect, covering entire seal area
2.2	25, Small size blisters on the inner side; on 4; L = 4'' small blisters
2.3	20, From 4'' from the corner 2 blisters, one major, L = 1/8'' inside the seal,
2.4	30, Two regions, one right next to corner, 1½'' small blisters
3.1	20, Some blisters are critical, inner edge, 2 regions, L = 1'' and 2½''
3.2	25, Lot of small blisters, 5-6 blisters critical, inner edge, L = 3''
3.3	25, Most of the blisters are critical, inner edge L = 2''
4.1	30, Air bubble inside the seal L = 1/2''; One blister on 4; dia = 1/8", 1/16"
4.2	20, one blister, right on the corner, very small, inside 1/8"
4.3	25, Two regions; 5" apart, L = 1½", two of them critical on the inner edge, 2 on the corner
4.4	25, Blisters on all sides of the package
5.1	20, one blister of dia = 1/16"
5.2	25, some bubbles on the side 2; one bubble on corner of side 4; dia = 1/16" and 1/8" inside the seal
5.3	25, L = 4½"; the blisters in this region, almost all are on the inner edge and critical
5.4	15, The region of bubbles on corner, of lengths = 3 and 5"
5.5	20, The bubble of dia = 1/16", on the inner edge, critical
6.1	25, L = 2", small in size, only one runs through the entire length of seal
6.2	20, Cluster of blisters around the corner, on 2 one blister at L = 5½" in diameter = 1/6"
6.3	25, L = 4½", scattered blisters almost all on the outer edge, except one
6.4	20, The blisters are scattered on side 2, very small
7.1	20, Lot of blisters, right on the inner side of seal, L = 2", one big blister, dia = 1/16"
7.2	20, one blister on 4, outside; L = 1", 4-5 blisters, outside, tiny; on the corner, lot of blisters, tiny
7.3	25, on 3; one blister dia = 1/16", on 4; L = 6½", cluster on the inner edge

All of the trays with blisters in their seals in table E.1 contained chicken breast with gravy.

Table E.2: Defective trays with blisters in their seals from Vendor 3.

Sample Number	Pressure (psi)	Comments
1.1	35	L = 3/16", on the corner, seal width = 5/16"
1.2	30	L = 2/16", on the inner edge, 31/2" from the bottom
1.3	35	Diameter = 2/16", right on the edge
1.4	40	on the corner, seal with = 4/16", diameter = 1/16"
1.5	35	The defect is on the corner, dia = 2/16"

All of the trays contained mashed potatoes with chicken.

Table E.3: Defective trays with delamination from Vendor 1.

Sample No	**Pressure (psi) and Comment**
1.1	20, Only a wrinkle across the seal, about 3" from the corner
1.2	20, Bubbles + Delam L = 2"; EM on the inner edge L = 2/16" about 3" from bottom corner Bubbles + Delamination on bottom corner
1.3	20, Three distinct regions of delamination: L = 3/4", 1/2" and one across the corner. Bubbles on 4; L = 2/16" seal = 4/16"
1.4	25, Delamination on the outer edge, L = 1/2"
1.1	25, EM L = 1/4", small; EM L = 1/8" small; Delamination in the form of tunnels W = 1/16",L = 1½"
1.2	20, Three Delamination regions: L = 6/16", on the corner; L = 5/16", entire seal width; W = 2/16"; L = 2/16"
1.3	20, Delamination in the form in the tunnels; L = 1/2" W = 1/16"; other Delamination; 4" from bottom corner; L = 1/4"
1.4	20, Negligible width; L = 1/16"; 4½" from bottom corner
1.1	25, 3" of delamination in the form of tunnels, W = 1/16"; some bubbles on the inside seal
1.2	20, L = 3/4" of tunnel delamination
1.3	25, two EM defects; L = 2/16" W = negligible; other EM, really small
1.4	20, 2" of delamination, W = 1/16"

All of the trays contained chicken breast with gravy.

Table E.4: Defective trays from Vendor 3 with entrapped matter in their seals.

Sample No	Pressure (psi)	Comment
1.1	35	Air bubble diameter = 2/16" right on the end of the corner
1.2	40	EM + short seal, short seal; L = 7" and W = 3/16"
1.3	45	Diameter = 2/16", seal width = 5/16", defect inside
1.4	40	Diameter = 4/16", almost covers the entire seal width.
2.1	30	Short seal + EM; on 3; seal w = 3/16"; blister on the corner diameter = 1/16"
2.2	40	Short seal + EM; on 3; L = 7"; W = 3/16"; EM on 2; diameter = 2/16",
2.3	40	Wrinkles + Short seal; seal L = 7", W = 3/16"
2.4	35	Wrinkles + Short seal; seal L = 7", W = 3/16", Wrinkles on the corner; entire seal width and other location; L =1/4"; outside

Trays 2.3 and 2.4 contained blueberry dessert while the rest contained mashed potatoes with chicken.

Table E.5: Defective trays from Vendor 1 with entrapped matter in their seals.

Sample No	Pressure (psi)	Comment
1.1	25	Entrapped matter, small bubbles, L = 2" well inside the seal
1.2	25	3 major spots, covering the entire seal width, 1/8",1/2" and 1/8" respectively
1.3	20	various small spots, L = 6"
1.4	25	2 spots, very small in size, one on the corner, and the other 2" from the bottom corner.
2.1	25	on 3 two major voids, entire seal width, on 1, EM, about 2/16"
2.2	20	on 3, EM, L = 1/16"; on 1, EM, L = 2"
2.3	25	on 3,two major defects, 2/16" and 5/16" and short seal on 4;3-4/16"
2.4	20	EM on 3, at the corner L = 3/16",dia = 1/6"; on 4; blisters along the length of 4

All of the trays contained chicken breast with gravy.

Table E.6: Defective trays with short seals from Vendor 3.

Sample No	Pressure (psi)	Comment
1.1	40	runs 7' and seal width 5/16''
1.2	40	L=6¼', extends across corners, width = 1/4''
1.3	35	L = 7', W = 1/4''
1.4	40	L = 7', W = 1/4',
2.1	40	L = 7', W = 3/16''
2.2	40	L = 7', W = 3/16''
2.3	30	L = 7', W = 3/16''
2.4	40	L = 7', W = 3/16'', across corner = ¼''
3.1	35	L = 7', W = 3/16''
3.2	40	L = 6¼'', W = 2/16'', across left and right corner = 3/16''
3.3	40	L = 63/4', W = 3/16'', across left corner = 1/4''
4.1	40	L = 7', W = ¼'', Entrapped moisture on 1st side, Diameter = 1/8''
4.2	25	L = 7', W = 1/4''
4.3	35	L = 7' on either side, on side 3, W = 3/16'', side 1, W = 3/16''
4.4	40	L = 7', W = 3/16'', Entrapped moisture on face 1, Diameter = 1/8''
5.1	40	Nor a short seal, wrinkles across side 2.
5.2	40	L = 5½'', W = ¼'', across right corner, W= 3/16''
5.3	35	L = 7', W = 3/16''
5.4	40	L= 7', W = 3/16''
6.1	40	L = 7', W = 1/4'', Entrapped moisture on 1
6.2	40	L = 7', W = 1/4'', Entrapped moisture on 2
6.3	40	L = 4½' for 1/4th of an inch, and 2½'' for 3/16th of an inch.
6.4	40	L = 7' , W = 3-4/16''

Table E.7: Defective trays with short seals from Vendor 1.

Sample No	Pressure (psi)	Comment
1.1	30	L = 7', W = 1/8" across corner 3/16', sort seal on all the side, 3/16"
1.2	40	L = 7', W = 1/8" on side 2, L = 9½" of W = 3/16", on side 4, L = 9', W= 3/16"
1.3	35	L = 7½ and W = 1/8"
1.4	30	Across 1, L = 7½" W = 1/8" and across 4, L = 9½", W = 3/16"
2.1	35	on 1; L = 7', W = 1/4",on 2; L = 2½" and W = 3/16', on 3; L = 4½", W = 3/16"
2.2	25	But critical defect on the inner edge, L = 6½" and W = 1/8"
2.3	25	on 2; L = 6' and W = 3/16", on 3; L = 7', W = 3/16", on 4; for L = 5½", W = 1/8', rest W = 3/16'
2.4	25	Short seal on all the faces, W = 3-4/16'
2.5	25	Short seal on all the faces, W = 3-4/16'

All of the trays contained chicken breast with gravy.

Table E.8: Trays with tunneling defects in their seals from Vendor 1.

Sample No	Pressure (psi)	Comment
1.1	20	One large tunneling defect about 5½" from the corner, and a couple of small
1.2	25	on 1; two tunneling defects (TD), small in size, about 1/16"; and air bubble, diameter = 2/16" separated by about 4½"
1.3	25	on 4, Two TD, one very small on the inner edge; other separated by 1½"; has 2 defects, one 2/16" and other small
1.4	25	Cluster of 3-4 small TD, the bigger one, w = 2/16"
1.5	20	on 2, L = 2/16" other small TD; on the bottom corner of 4; air bubbles, small in diameter
2.1	20	on 2; TD, diameter =1/32",L = 1/16"; from 6" from the corner, on 3; 2 TD; both diameter = 1/32" entire seal width
2.2	25	one TD; entire seal width, really small width
2.3	30	EM, diameter = 1/16" about 5" from the corner; TD, L = 2/16", small width
2.4	25	on 1; 2 TD; both diameter = 1/32", entire seal width; 4/16"; TD on 4; L = 2/16" small in width
3.1	20	One TD, L = 3/16", small width; one EM, outer edge, very small
3.2	25	Scattered bubbles on two sides, near the seal; a bubble on the corner; Diameter = 2/16"; seal = 4/16"
3.3	25	EM: on 2, diameter = 2/16" inner side; on 3 EM of L = 1"; on 4, 4" of bubbles on the seal
3.4	20	on 2; TD outside; diameter = 1/16" seal = 4/16"; on 3; TD, seal = 4/16", diameter = 2/16"

All of the trays contained chicken breast with gravy.

Appendix F: Instrumented Burst Test Procedure

1. Prepare the polytray to be tested by drilling a 1 inch hole in the middle of one of the short sides of the tray.
2. Place the rubber stopper fitted around the air supply hose into the drilled hole, place polytray into holding frame, and then slide the frame into the burst chamber.
3. Place the burst chamber in a container (a plastic box works well) to contain food from burst tray.
4. Connect the burst test unit to a source of compressed air of at least 60 psi but not more than 150 psi with a fitting to accommodate a 1/4"-18 standard male pipe fitting.
5. Launch the "STP_2011_Burst_Test.exe" program.
6. Click on the LEAK TEST button and wait 5 minutes to ensure that the Air Flow Rate settles down to less than 0.4 cc/min. If this does not happen, stop test by clicking on STOP, check all connections for a leak, and start over.
7. If the Air Flow Rate settles down to less than 0.4 cc/min, press BURST TEST button to apply 25 psi test pressure to tray.
8. Wait 5 minutes. If the tray does not burst in this time and if the Air Flow Rate settles down to less than 0.4 cc/min, the polytray passes the test. If either of these conditions are not met, the polytray fails the test.
9. Press the STOP button, remove tray, and test another try if desired.